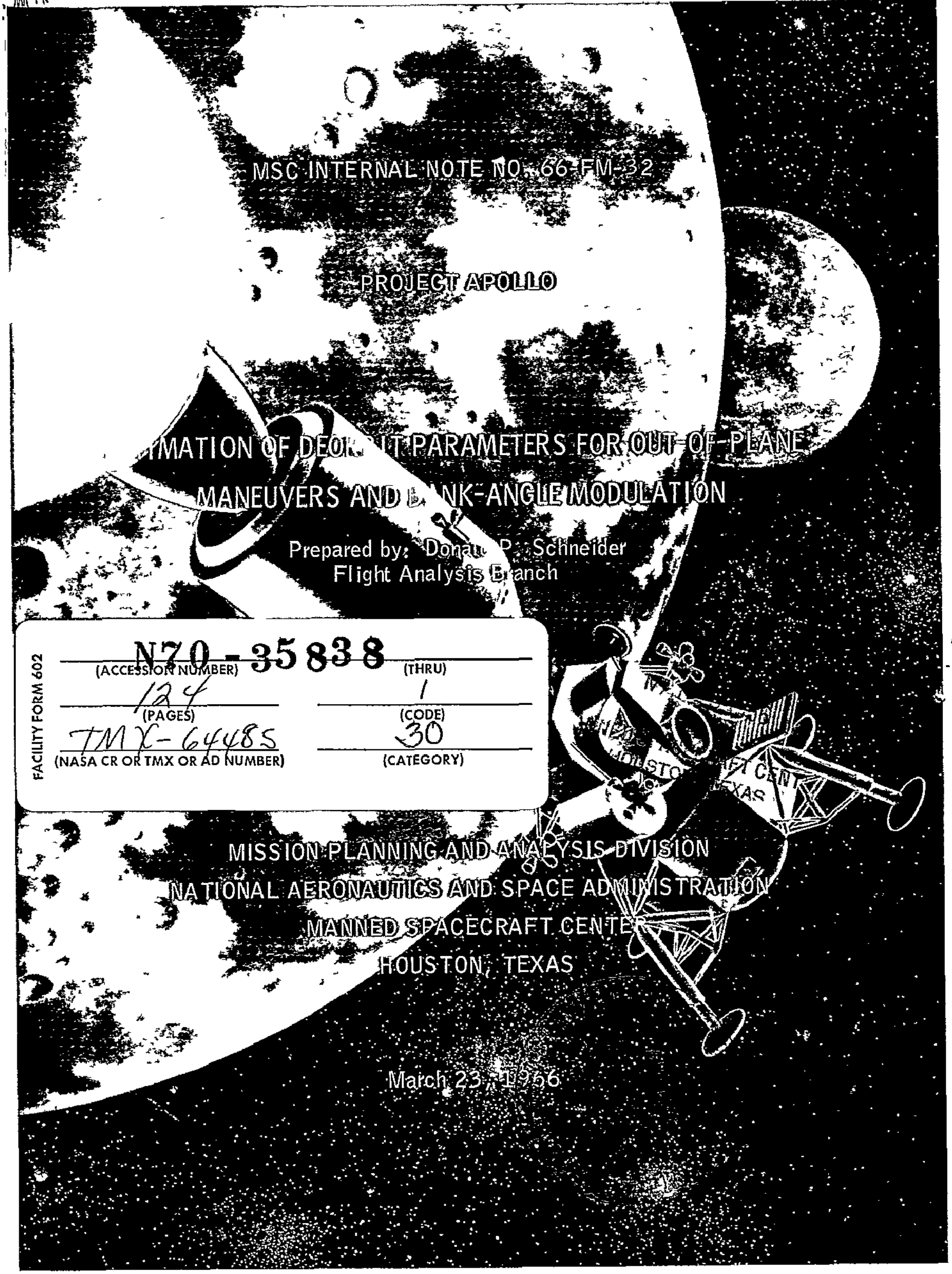


MSC INTERNAL NOTE NO. 66-FM-32

PROJECT APOLLO

ESTIMATION OF DEORBIT PARAMETERS FOR OUT-OF-PLANE MANEUVERS AND BANK-ANGLE MODULATION

Prepared by: Donald P. Schneider
Flight Analysis Branch

MISSION PLANNING AND ANALYSIS DIVISION
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MANNED SPACECRAFT CENTER
HOUSTON, TEXAS

March 23, 1966

MSC INTERNAL NOTE NO. 66-FM-32

PROJECT APOLLO

ESTIMATION OF DEORBIT PARAMETERS FOR OUT-OF-PLANE MANEUVERS AND BANK-ANGLE MODULATION

Prepared by: Donald P. Schneider
Flight Analysis Branch

March 23, 1966

MISSION PLANNING AND ANALYSIS DIVISION
NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
MANNED SPACECRAFT CENTER
HOUSTON, TEXAS

Approved: Carl R. Huss
Carl R. Huss, Chief
Flight Analysis Branch

Approved: John P. Mayer
John P. Mayer, Chief
Mission Planning and Analysis Division

CONTENTS

FIGURES

FIGURES

FIGURES

SUMMARY

This internal note presents data and examples which will enable the reader to estimate deorbit parameters for out-of-plane burns and bank-angle modulation. An attempt has been made to enable the reader to find the correct attitude of retrofire to achieve a given impact point with either out-of-plane burns or bank-angle modulation. A comparison was made to determine the difference in the amount of ΔV needed to achieve a given impact point with out-of-plane maneuvers and bank-angle modulation.

It is shown that out-of-plane burns require much more ΔV than bank-angle modulation to achieve a given impact point. However, out-of-plane burns give much greater variations in cross range and down range.

1.0 INTRODUCTION

This paper presents in graphs and tables the results of a study investigating the outcome of performing the deorbit maneuver and, at the same time, changing the orbital plane. This maneuver is being considered as a possible means of landing closer to a desired impact area. It is compared to the use of bank-angle modulation for accomplishing the same objective.

This study was particularly concerned with AS-204, but it may also be applied to other missions within the ranges of weights and ΔV's considered. The study includes combinations of pitch and yaw attitudes with various amounts of burn time and various orbital conditions. Special attention is given to the effect that latitude at retrofire and weight at retrofire has on down range and time from end of burn to impact. One section is devoted to the results of a study of cross range and down range with respect to the aerodynamic capabilities (i.e., by changing the lift vector orientation through bank-angle modulation) of the spacecraft.

2.0 METHOD OF ANALYSIS

Because of the vast differences in total reentry ranges caused by various ΔV's and initial orbits, it was necessary to define many "nominal" cases. A nominal case is one in which, for a given ΔV, the pitch attitude equals 0 deg, the yaw attitude equals 180 deg, and bank angle equals 0 deg. A nominal case has a nominal landing point; i.e., cross range and down range equal 0. All cross ranges and down ranges resulting from the various burn attitudes, bank angles, and excess propellant loadings are referenced to their own particular nominal case, which is represented by a retro ΔV and orbital condition.

2.1 Constraints

In preparing this study the following two items were used as major constraints:

a. Time of 5 min must remain above 300000 ft to perform command module/service module (CM/SM) separation and CM reentry attitude maneuver.

b. Reentry time (including parachute time) must be below 45 min (45 min measured from CM/SM separation to landing).

In extreme cases 20 g were used to rule out a particular reentry, but it should be noted that g loads were not used as a specific constraint. Range was not used as a constraint since the time line of 45 min usually was a restriction before ranges became excessive.

2.2 Range of Parameters

Nine deorbits were considered. Five were from an 85, 100, 150, 200, and 400 n. mi. circular orbits. The other four were at apogee and perigee of two elliptical orbits, 85/130 n. mi. and 85/400 n. mi. In these orbits, the range of some other parameters were as follows:

a. Spacecraft yaw attitude was varied from 180 to 105 deg. (When the pitch is 180 deg, a yaw of 180 deg is a direct retrofire.)

b. Spacecraft pitch attitude was varied from 0 to -60 deg (minus being pitch down from the inertial velocity vector).

c. Spacecraft bank angle was varied from 0 to 90 deg (0 being full positive lift).

d. Retrograde incremental velocity was varied from 400 ft/sec to 4000 ft/sec, depending on the orbit considered.

2.3 Performances

The service propulsion system (SPS) performance, I_{sp}, and flow rate used in this document are those specified in reference 2. The CM/SM weight (less SM propellant) was assumed to be 21200 pounds.

In cases where a specific ΔV, such as 500 ft/sec, is given, the SM was loaded with just enough propellant to achieve the given ΔV and leave no propellant remaining in the tanks after the burn. In order to calculate the correct amount of propellant to achieve a desired ΔV the following formula may be used:

$$W_o = W_f \cdot e^{\frac{\Delta V}{I_{sp}\, g_o}} \tag{1}$$

where

W_o = initial weight.

W_f = final weight.

g_o = gravity at sea level.

The propellant loading is then calculated by subtracting the final weight from the initial weight. The time of burn, t_b, is found by dividing the propellant loading by the flow rate.

2.4 Formulation of Cross Range and Down Range

Since there are many ways to define and compute cross range and down range, it is necessary to include the formulation used in this study for computing these parameters. A conventional coordinate system consisting of spherical polar coordinates (r = spherical radius, θ = co-latitude, ϕ = longitude) was used.

Two auxiliary spherical coordinate systems were also used.

The first of these auxiliary coordinate system (r, θ^*, ϕ^*) has its polar axis through the initial location of the vehicle and its prime meridian ($\phi^* = 0$) along the initial velocity vector of the vehicle; thus θ^* measures angular distance from the initial point and ϕ^* measures "lateral longitude" from the initial flight-path direction. The second auxiliary coordinate system (r, μ, ν) takes the initial location of the vehicle as the intersection of the equator and prime meridan; the equator ($\nu = 0$) is oriented along the great circle defined by the initial flight-path direction.

This information has been taken from reference 1.

The radius vector r is the same in all three coordinate systems. Knowing the nominal co-latitude, θ_0, longitude, ϕ_0, and the relative azimuth of the impact point, and the present co-latitude, θ, and longitude, ϕ, the down range from the nominal impact point can be calculated as follows:

$$\cos \nu \cos \mu = \sin \theta_o \sin \theta \cos (\phi - \phi) + \cos \theta_o \cos \theta \qquad (2)$$

After solving (2) for the angle μ, multiplying by the radius of the spherical earth, in feet, and dividing by the number of ft/n. mi., the down range is obtained in units of n. mi. from the nominal impact point.

In like manner to find cross range from nominal impact point use this equation:

$$\sin \nu = \sin \theta_o \cos \theta \sin B_o - \sin \theta (\sin B_o \cos \theta_o \cos (\phi_o - \phi) + \cos B_o \sin (\phi_o - \phi) \qquad (3)$$

and solve for the angle ν. B_o is the direction of the initial velocity vector. The previously noted conversion factors are used to find cross range in n. mi.

3.0 RESULTS AND DISCUSSION

There are two main sections to this paper. The first section (figure 1-9) consists of various cross ranges and down ranges which result from different burn attitudes, orbital conditions, latitudes, ΔV's, and excessive weights. The second section is concerned with the effect bank-angle modulation has on the cross range and down range.

In the first section either cross range or down range is plotted against yaw attitude for various pitch attitudes (see figures 1 to 9). For any figure the orbital conditions and ΔV for retrofire are a constant. The data presented in the figures have a bank angle of 0 deg, a latitude of 32 deg at retrofire, a relative azimuth of 90 deg, and no excessive propellant.

In the second section (see figure 10), no excess weight was considered and all retrofires occurred at 180 deg yaw attitude and 0 deg pitch attitude, i.e., a direct retrofire. For bank angles greater than 0 deg, it became apparent that impacts always occurred up range from the nominal and the time that CM/SM separation to impact decreased as the bank angle increased. G forces sometimes became excessive as the bank angle was increased.

3.1 Pitch Attitude with Bank-Angle Modulation

All the data shown in figure 10 represents a pitch attitude of 0 deg. To correlate bank angles with pitch attitudes other than 0 deg, first obtain the down range which results from the selected pitch attitude from figure 1 to 9. The resulting down range can be found be algebraically adding the down range values obtained from figures 1 to 9 to that obtained from figure 10.

3.2 ΔV Requirements for Bank-Angles and Out-of-plane Maneuvers to Achieve Maximum Cross Range

When bank-angle modulation is compared to out-of-plane maneuvers as means of achieving the desired cross ranges, one of the questions which arises is the amount of propellant that is necessary to achieve the same impact point. The following table shows the ΔV required by bank-angle modulation and by out-of-plane burns to achieve the same impact point for a given cross range.

Orbit in n. mi.	Cross Range in n. mi.	ΔV for bank-angle modulation	ΔV for out-of-plane
85 circular	86	400	650
100 circular	81	400	805
150 circular	76	400	771
200 circular	72	400	589
400 circular	62	1000	1149
85/150 (burn at perigee)	84	400	802
85/150 (burn at apogee)	77	400	493
85/400 (burn at perigee)	85	1000	1020
85/400 (burn at apogee)	68	400	728

This table was compiled by taking from figure 10 the maximum cross range possible from bank-angle modulation with the corresponding ΔV for each of the orbital conditions considered. Then the ΔV was computed for an out-of-plane burn to achieve the same cross range. In both cases the ΔV's computed gave reentries which did not violate the constraints given in section 2.1.

4.0 APPLICATION OF DATA

There are several prerequisites necessary to make use of the data in this study. The ellipse being considered must be approximately equivalent to one of the orbits considered in this study, a time of burn must be selected, and the impact point with a spacecraft, which carries no excess propellant, must be located for a direction retrofire. Equation (1) enables the correct amount of propellant to be found for a specific burn time. Due to the number of parameters considered and the graphs of the data, its use is limited to finding a close approximate answer to a boundary value problem before iteration methods are applied. It should be noted that figure 11 and table I and II do not apply to figure 10, which is concerned with bank-angle modulation. The three examples which follow should clarify the steps necessary to compute the required attitude at retrofire or bank angle required to achieve the desired impact point.

4.1 Example of Calculations for an 85 n. mi. Circular Orbit for an Out-of-Plane Maneuver

Consider an 85 n. mi. circular orbit, with a selected t_b of 12.6 sec, (see Appendix for ΔV), an excess propellant loading of 3000 pounds, and a retrofire at 16 deg latitude. First, the nominal deorbit is computed for a direct retrofire and a propellant loading of 863 pounds, as calculated from equation (1). Suppose the impact point for the nominal deorbit is calculated from equations (2) and (3) to be 30 miles cross range and 300 miles up range from the desired impact point. The problem is to determine what pitch and yaw to burn at to achieve the desired impact point.

The first step is to read from figure 11 the Δ down range which will result from an excess propellant loading of 3000 pounds. For the given t_b and excess propellant loading, the correction for down range is 260 n. mi. This revision makes a new <u>reference</u> down range of 40 n. mi. Cross range was found to be relatively insensitive to excess propellant loadings.

Using figure 1-a, make a table of all the combinations of pitch and yaw that will produce the desired down range and make a similar table for the desired cross range. Plotting this data results in the dotted curves shown in figure 12.

Cross Range = 30		Down Range = 40	
Pitch	Yaw	Pitch	Yaw
-60	107.5	-60	118
-45	130	-45	122.5
-30	140	-30	130
-20	145	-20	137.5
0	151	0	169

This table shows that there are two initial solutions for the correct attitude of retrofire. These two solutions are indicated by the intersections of the curves dotted in figure 12. We will look at one of the solutions; the other could be found in the same way. One solution lies between a pitch of -60 deg to -45 deg and a yaw of 118 deg to 122.5 deg, since there is a corresponding pitch and yaw on both the cross range half and the down range half of the table.

Now to use table I read from figure 12 the initial solution for 119 deg. Make a straight line interpolation between 32 deg and 0 deg latitude; the correction in cross range is -1.5 n. mi. and the correction in down range is 96.5 n. mi. Therefore, the new reference cross range is 31.5 n. mi. and the new reference down range is -56.5 n. mi.

Now make a table for the new reference cross range and down range.

Cross Range = 31.5		Down Range = -56.5	
Pitch	Yaw	Pitch	Yaw
-60	105	-60	122.5
-45	127.5	-45	126.0
-30	138.5	-30	134
-20	143.5	-20	142
0	149.5	0	---

When the points in the above table are plotted, they will give the solid curves in figure 12. A solution for the correct attitude of burn occurs at an intersection of the down range and cross range lines. In this case the correct pitch was found to be -45.43 and the correct yaw was 126.85.

This combination of pitch and yaw is now designed to give a Δ down range of 300 n. mi. and a Δ cross range of 30 n. mi. when used in an integrated trajectory with the excess propellant onboard and the retrofire at 16 deg latitude. As was previously stated, the solution will probably not be exact because of the many pertubations involved, but its use lies in boundary value problems as a first guess for iteration techniques. If a simpler interpolation is desired, the section involved with latitude corrections may be omitted.

4.2 Example of Calculations for a 150 n. mi. Circular Orbit

For the second example we will consider a 150 n. mi. circular orbit, with a selected t_b of 32.4 sec, an excess propellant loading of 1500 pounds, and a retrofire at 8 deg latitude. For a direct retrofire and no excess propellant loading, the desired impact point from equations (2) and (3) is calculated to be 70 n. mi. cross range and 400 n. mi. up range from the nominal impact point.

Again the first step is to determine what correction in down range must be made because of an excess propellant loading. For the given t_b, orbital conditions, and excess propellant, the correction from figure 11-c is 170 miles. Therefore, the new reference down range is 230 n. mi.

Step two is again the compilation of a table of pitch and yaw attitudes that will produce the desired cross range and down range.

Cross Range = 70		Down Range = 230	
Pitch	Yaw	Pitch	Yaw
-60	---	-60	116
-45	126	-45	119.5
-30	139	-30	126.5
-20	143.5	-20	132.5
0	150	0	154

From this table it can be seen that an answer lies between pitch attitudes of 0 to -20 deg and between yaw attitudes of 143.5 deg to 150 deg. Again making a two-way straight-line interpolation for an estimated yaw = 149 deg in table I, the correction for cross range is 1.75 n. mi. The new reference cross range is 68.25 n. mi. and the new reference down range is 223.5 (230 - 6.5) n. mi. In this case, latitude corrections were shown to be relatively small.

Now make a table for the new reference cross range and down range.

Cross Range = 68.25		Down Range = 223.5	
Pitch	Yaw	Pitch	Yaw
-60	---	-60	116
-45	127.5	-45	119.5
-30	140	-30	127
-20	144.5	-20	132.75
0	151	0	154.25

To solve for the correct answer, again use a figure similar to figure 12.

From the graph, the correct pitch is -4.33 deg and the correct yaw is 149.6 deg.

When an integrated trajectory was run with the above calculated pitch and yaw, the cross range was found to be 66 n. mi. and the down range was found to be 332 n. mi. If a more accurate solution is needed, figure 3-d may be used again. Using this figure, note the down range corresponding to a yaw of 149.6 deg. Add to this down range the needed 68 miles down range (400 n. mi. -332 n. mi.) and read the corresponding yaw. In this case the new yaw is 146.3, which, when run in an integrated trajectory, gave a cross range of 70 n. mi. and a down range of 411 n. mi. Since the total range was about 3000 n. mi., the percentage error of 11 out of 3000 was very small. Thus, these burn attitudes may be used in a boundary value program as a very close first guess to the required attitudes.

4.3 Example for Bank-Angle Modulation

In some cases it may be desirable to use bank-angle modulation as a means of achieving a desired impact point. For an example, consider a 100 n. mi. circular orbit and a $t_b = 32.36$ sec. Suppose that for a direct retrofire and 0 deg bank angle, the nominal impact point is found to be 200 miles down range from the desired impact point.

By looking at figure 10-b, it can be seen that a bank angle of 42.5 deg will give the desired down range of -200 n. mi. from the nominal. This bank angle in turn will give (from figure 10-b) a cross range of 78.5 n. mi.

Here again (as explained in section 2.0) each of the deorbits shown in figure 10 is referenced to some nominal run (for its own particular ΔV).

5.0 CONCLUSIONS

It can be seen from the data in this paper that use of yaw attitude variations during retrofire, in nearly every case, requires far more propellant to achieve a desired cross range than is required to achieve the same cross range through bank-angle modulation. Out-of-plane burns, on the other hand, give much greater flexibility in selection of cross range and down range. In general, they can give greater variation in cross range, and positive or negative down ranges. However, one point about bank-angle modulation should be brought out. As the bank angle increases from 0 deg to 90 deg the time from CM/SM separation to impact

is steadily decreased - in some cases it is decreased by nearly 350 sec. In addition, g loads sometimes became excessive as the time was radically decreased.

As more excess propellant is available the power-supply-time limit line should be considered since the time from CM/SM separation to impact increases with an increase in excess propellant loading.

APPENDIX

PERTUBATIONS

There are several major factors which cause pertubations in figures 1-9. These figures were plotted with the assumptions that all the available propellant was burned up, the power-supply-time limit line was not exceeded, and all retrofires occur at 32 deg latitude. To account for these assumptions figure 11 and table I and II should be used.

Excess Propellant Loading

To find corrections in figure 1-9 due to excess propellant, figure 11 must be used. In figure 11, t_b's are used in place of ΔV's. An example should help clarify the reason for this change of parameters.

In figures 1-9, a t_b = 12.6 sec and 0 pounds excess propellant is equivalent to a ΔV of 400 ft/sec, but as excess propellant is added, the ΔV is no longer equal to 400 ft/sec. Therefore, to correlate t_b's and ΔV's to make the needed corrections in figures 1-9 from figure 11, the following equalities should be noted (when all the propellant available is burned up):

a. t_b of 12.6 sec = ΔV of 400 ft/sec.

b. t_b of 15.8 sec = ΔV of 500 ft/sec.

c. t_b of 19.0 sec = ΔV of 600 ft/sec.

d. t_b of 32.4 sec = ΔV of 1000 ft/sec.

e. t_b of 68.1 sec = ΔV of 2000 ft/sec.

f. t_b of 151.3 sec = ΔV of 4000 ft/sec.

As was noted in section 2.0 a nominal case was defined be each particular ΔV and given ellipse. Because of this fact it is not possible in figure 11 to interpolate between time of burns given. However, on the same figure it is possible to interpolate between the excess propellant loadings.

Latitude Corrections

The latitude at retrofire also causes pertubations in figures 199. Tables I and II give errors encountered in cross range and down range

at 0 deg latitude with respect to 32 deg latitude. Here again, an example will clarify the use of the table. In reading the table for an 85 n. mi. circular orbit and a yaw of 135 deg the error in cross range is -6 n. mi. and the error in down range is found to be 79 n. mi. This error is for a retrofire at 0 deg latitude. To correct for a particular retrofire latitude, a straight-line interpolation will give the needed result. For instance, a retrofire at 16 deg latitude in the preceding case would require a correction of -3 n. mi. cross range and 39.5 n. mi. down range in figure 1. Since pitch does not affect latitude corrections nearly as much as yaw, it was discounted for practical reasons.

Power-supply-time Limit Lines

Figure 11 gives one other piece of information which should be considered when excess propellant is available. As the weight of excess propellant increases, the time from CM/SM separation to impact also increases (due to less effective ΔV). Therefore, the entry power-supply-time-limit line should be considered. It should be noted that all points plotted in figures 1-9 satisfy the time constraints listed in section 2.1. In figure 11, for example, for a burn time of 12.6 sec and an excess propellant loading of 10000 pounds, the power supply time is exceeded, whereas for no excess propellant is fell within the time constraints listed in section 2.1.

TABLE 1. - CORRECTIONS FOR FIGURES FOR RETROFIRES AT 0° LATITUDE FOR CIRCULAR ORBITS

Orbit	ΔV fps	Yaw deg	Δ CR n. mi.	Δ DR n. mi.
85	400	165	-2	4
		150	+3	27
		135	+6	79
		120	-3	193
	500	165	-2	1
		150	+2	19
		135	+7	60
		120	+3	152
	600	165	-2	-2
		150	+2	14
		135	+8	47
		120	+7	125
	1000	165	-3	-4
		150	+1	4
		135	+9	22
		120	+13	67
		105	-15	216
100	400	165	0	6
		150	+2	30
		135	+3	82
		120	-15	188
	500	165	-2	3
		150	+3	21
		135	+6	63
		120	-5	155
	600	165	-2	0
		150	+2	16
		135	+7	51
		120	-10	130
	1000	165	-2	4
		150	+1	5
		135	+7	24
		120	+10	72
		105	-11	221
	2000	165	-3	-6
		150	0	-3
		135	+7	7
		120	+14	29
		105	+2	108

TABLE 1. - CORRECTIONS FOR FIGURES FOR RETROFIRES AT 0° LATITUDE FOR CIRCULAR ORBITS - Concluded

Orbit	ΔV deg	Yaw deg	Δ CR n. mi.	Δ DR n. mi.
150	400	165	+6	8
		150	0	9
	500	165	+1	6
		150	0	26
		135	-7	51
	600	165	0	4
		150	+1	20
		135	-2	53
	1000	165	-3	-2
		150	+2	7
		135	+6	29
		120	+13	77
	2000	165	-3	-6
		150	+1	-2
		135	+7	8
		120	+9	35
		105	-36	-115
200	500	165	+3	9
		150	-3	22
	600	165	+2	7
		150	-1	21
	1000	165	-2	-1
		150	+1	9
		135	+1	30
		120	-21	81
	2000	165	-4	-7
		150	+2	-1
		135	+8	9
		120	+5	36
		105	-72	106
	4000	165	-3	-6
		150	+1	-3
		135	-2	6
		120	-1	28
		105	-51	93
400	1000	165	-2	3
	2000	165	-3	-4
		150	0	1
		135	0	10
		120	-33	31

TABLE II. - CORRECTIONS FOR FIGURES FOR RETROFIRES AT 0° LATITUDE FOR ELLIPTICAL ORBITS

Orbit	ΔV fps	Yaw deg	Δ CR n. mi.	Δ DR n. mi.
85/150 AP.	400	165	0	5
		150	+2	19
		135	-1	44
		120	-14	86
	500	165	-1	3
		150	+1	15
		135	+2	39
		120	-9	83
	600	165	-2	1
		150	+2	12
		135	+3	35
		120	-4	78
	1000	165	-2	-3
		150	2	4
		135	7	20
		120	5	55
		105	-40	135
	2000	165	-3	-6
		150	1	3
		135	8	6
		120	11	27
		105	-12	89
85/400 AP.	500	165	+3	3
		150	-1	4
	600	165	+1	0
		150	-1	3
		135	-6	8
	1000	165	-1	-4
		150	-2	2
		135	-2	9
		120	-21	20
85/150 PER.	400	165	0	14
		150	-3	65
		134	-5	188
	500	165	-1	7
		150	+3	40
		135	+3	123
		120	-40	353

TABLE II. - CORRECTIONS FOR FIGURES FOR RETROFIRES AT 0° LATITUDE FOR ELLIPTICAL ORBITS -Concluded

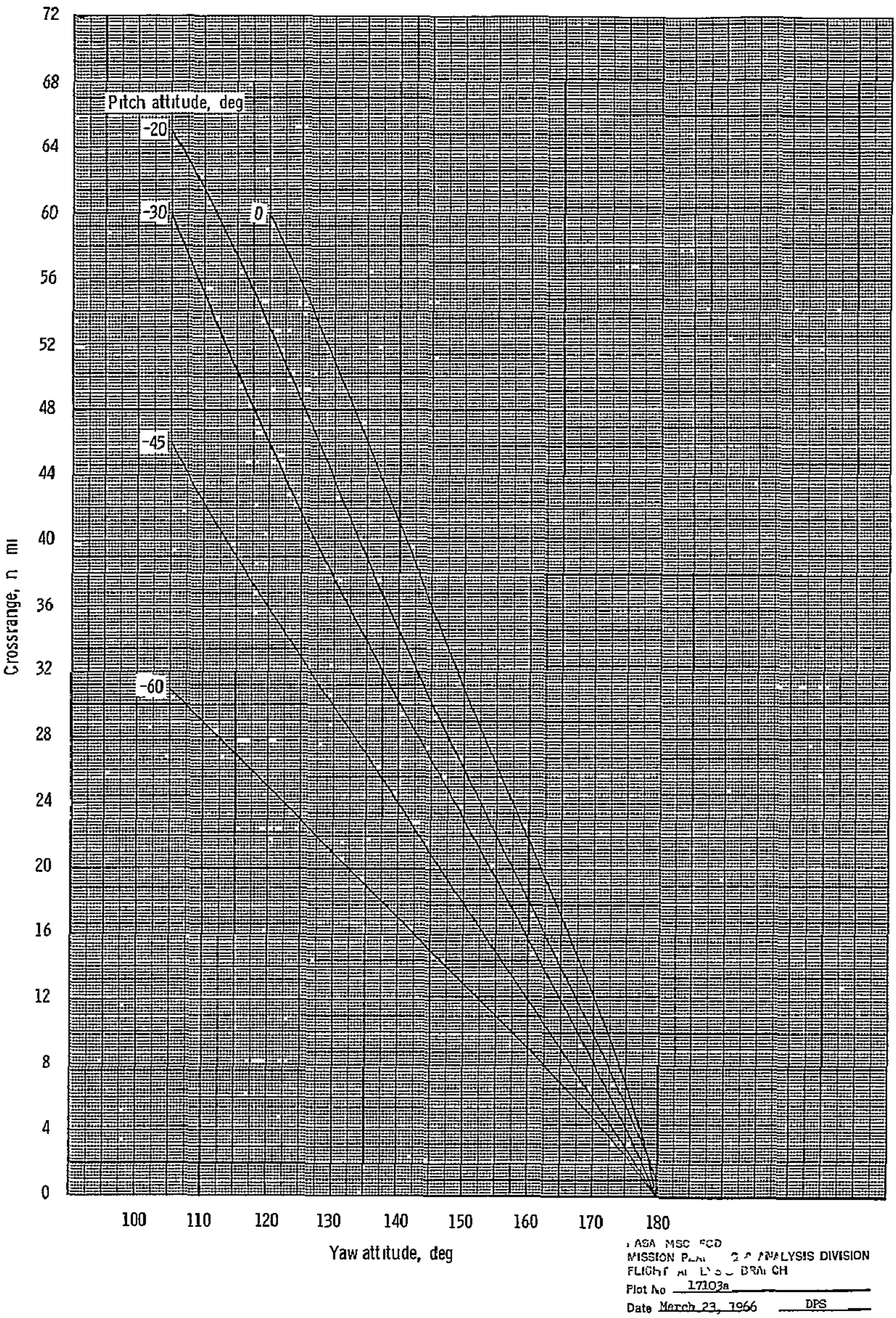
Orbit	ΔV fps	Yaw deg	Δ CR n. mi.	Δ DR n. mi.
	600	165	-2	3
		150	+3	27
		135	+7	88
		120	-17	256
	1000	165	-2	-2
		150	+2	9
		135	+9	35
		120	+11	108
85/400 PER.	1000	165	0	10
		150	+6	67
		135	-28	275
	2000	165	-2	-5
		150	+4	3
		135	+2	26
		120	+8	112

REFERENCES

1. A. E. Bryson, et al, Aerospace Engineering, "Optimum Lateral Turns for a Reentry Glider," pages 18-19, March 2, 1962.

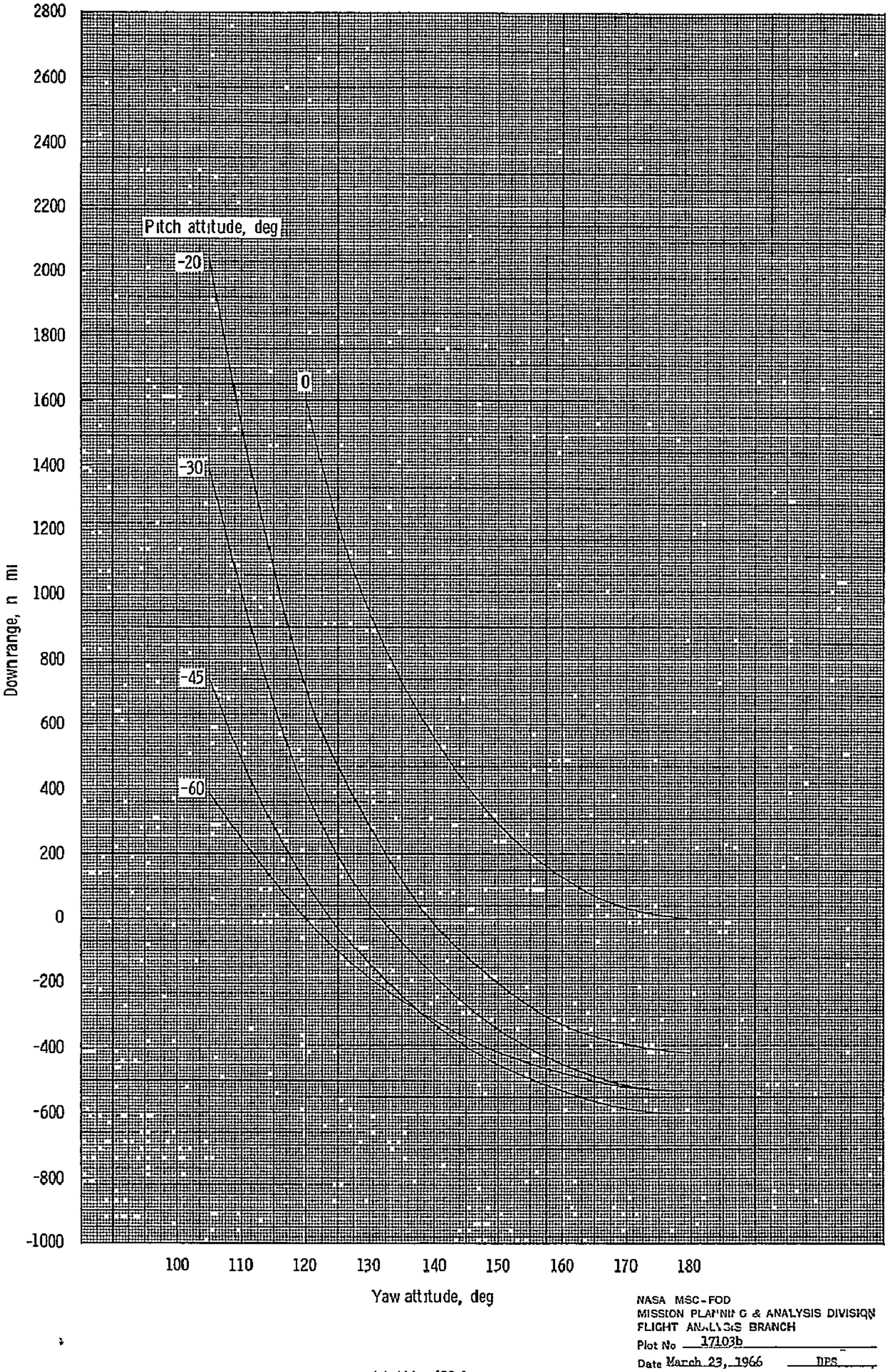
2. TRW Document, 3640-6003-TC-001, "Apollo Mission Data Specification Apollo Saturn 204A," dated June 24, 1965, (Unclassified).

3. MSC Internal Note No. 65-FM-45, "General Parametric Reentry Study for Near Earth Orbits," by Frank J. Suler, (Unclassified).



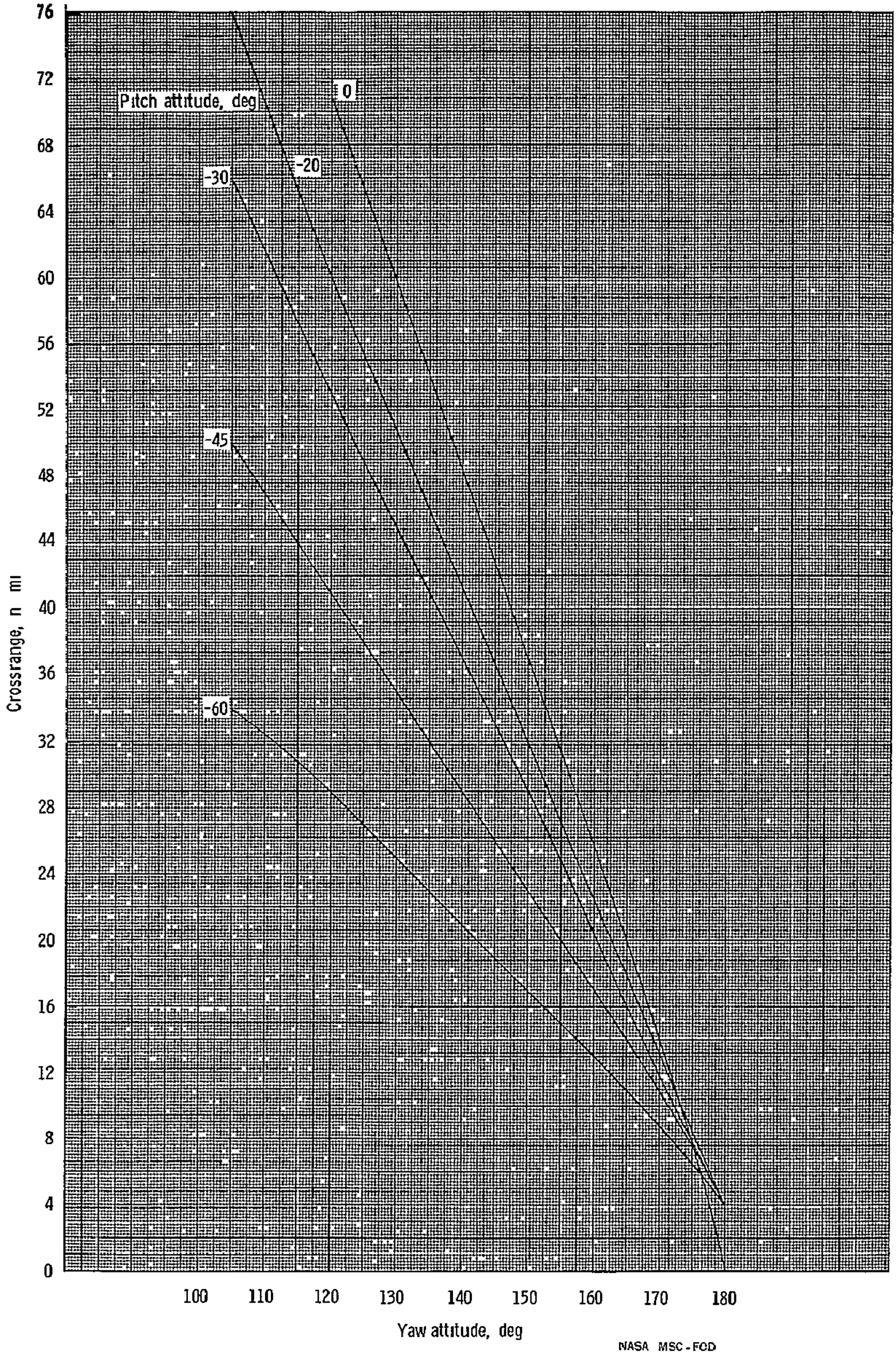
(a) ΔV = 400 fps

Figure 1. - 85 nautical mile circular orbit for various burn attitudes with downrange or crossrange versus yaw attitude for various pitches



(a) ΔV = 400 fps

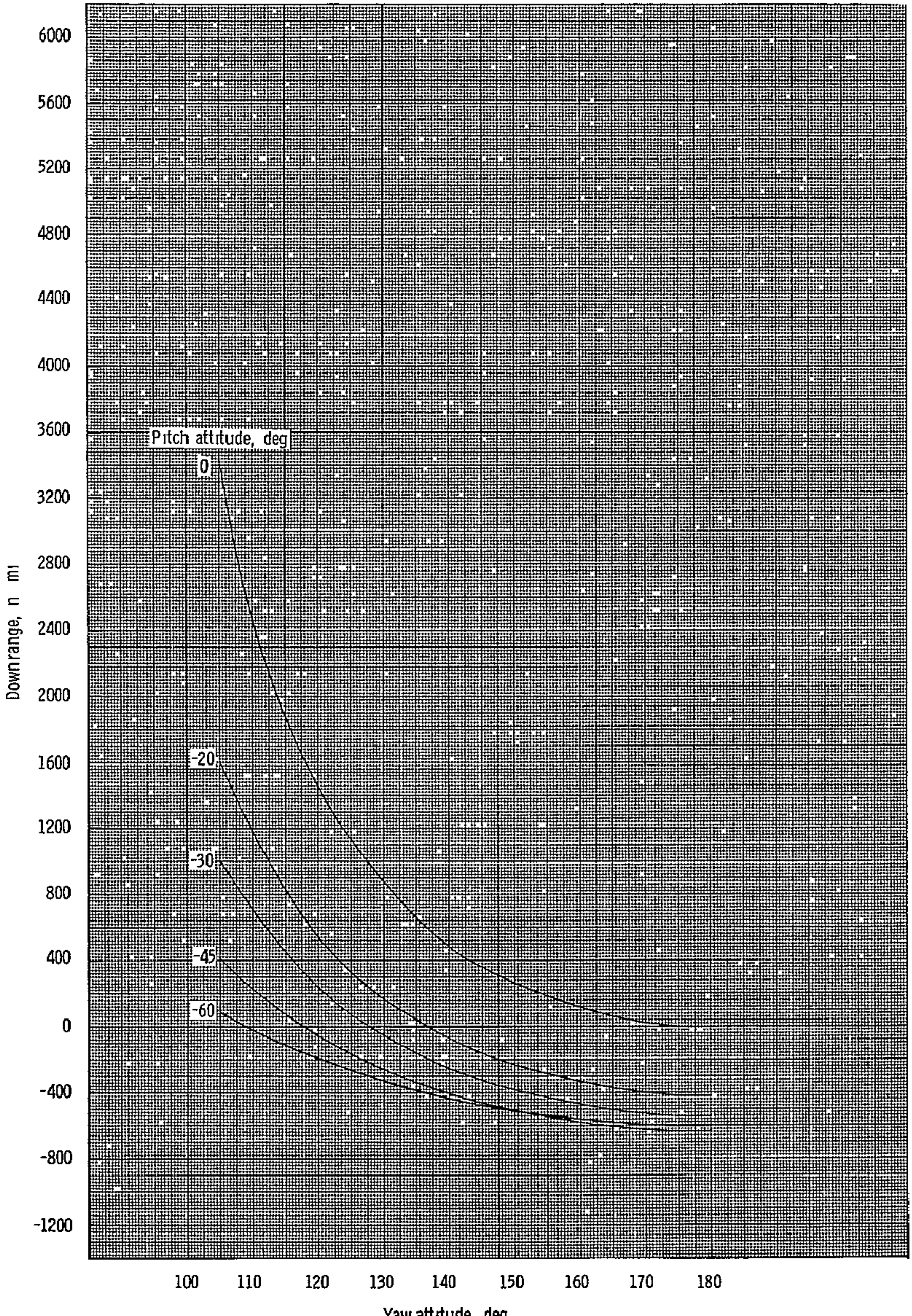
Figure 1. - Continued.



NASA MSC-FOD
MISSION PLANNING & ANALYSIS DIVISION
FLIGHT ANALYSIS BRANCH
Plot No 17103c
Date March 23, 1966 DPS

(b) ΔV = 500 fps.

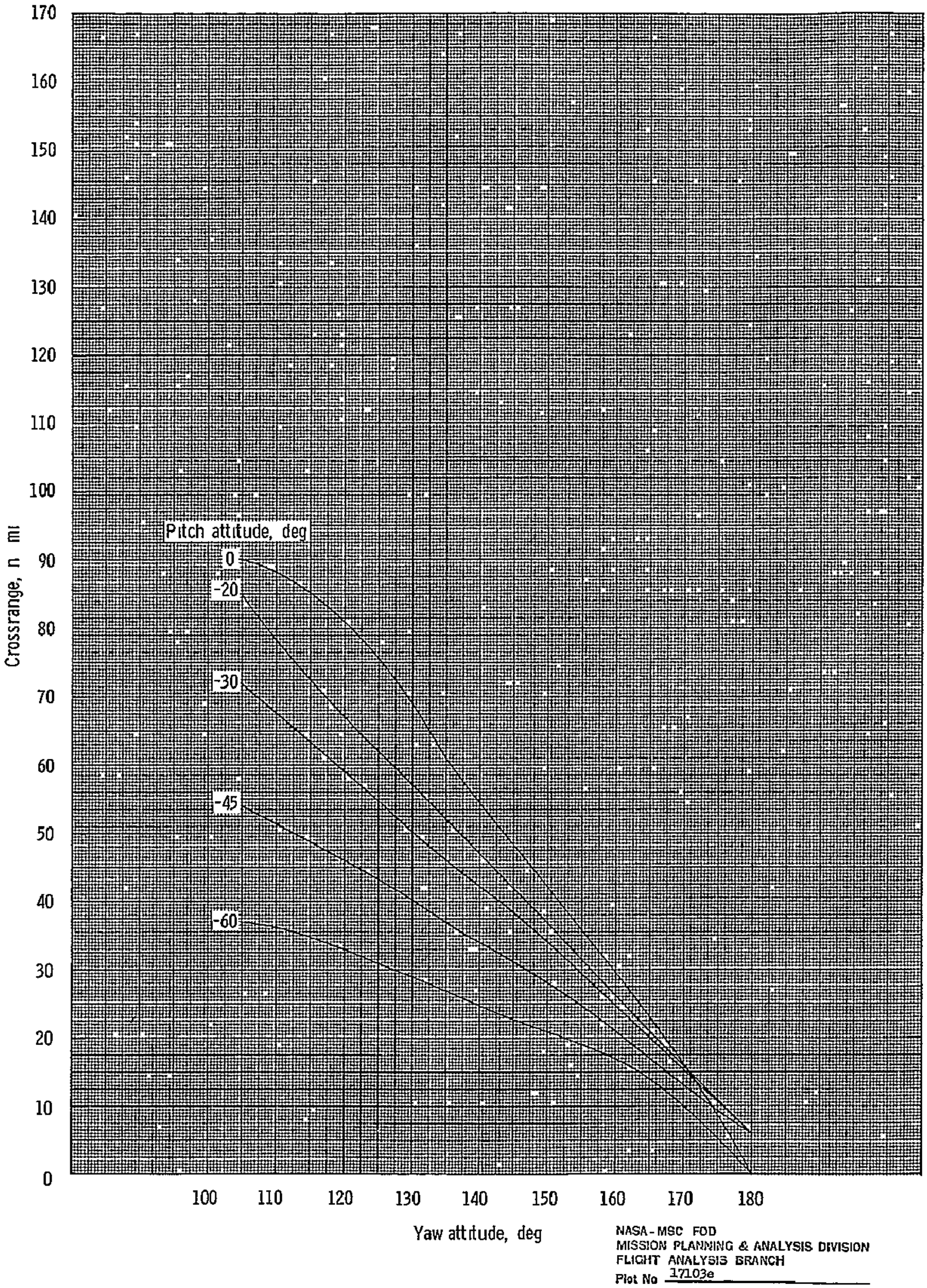
Figure 1. - Continued.



NASA - MSC - FOD
MISSION PLANNING & ANALYSIS DIVISION
FLIGHT ANALYSIS BRANCH
Plot No 17103d
Date March 23, 1966 DPS

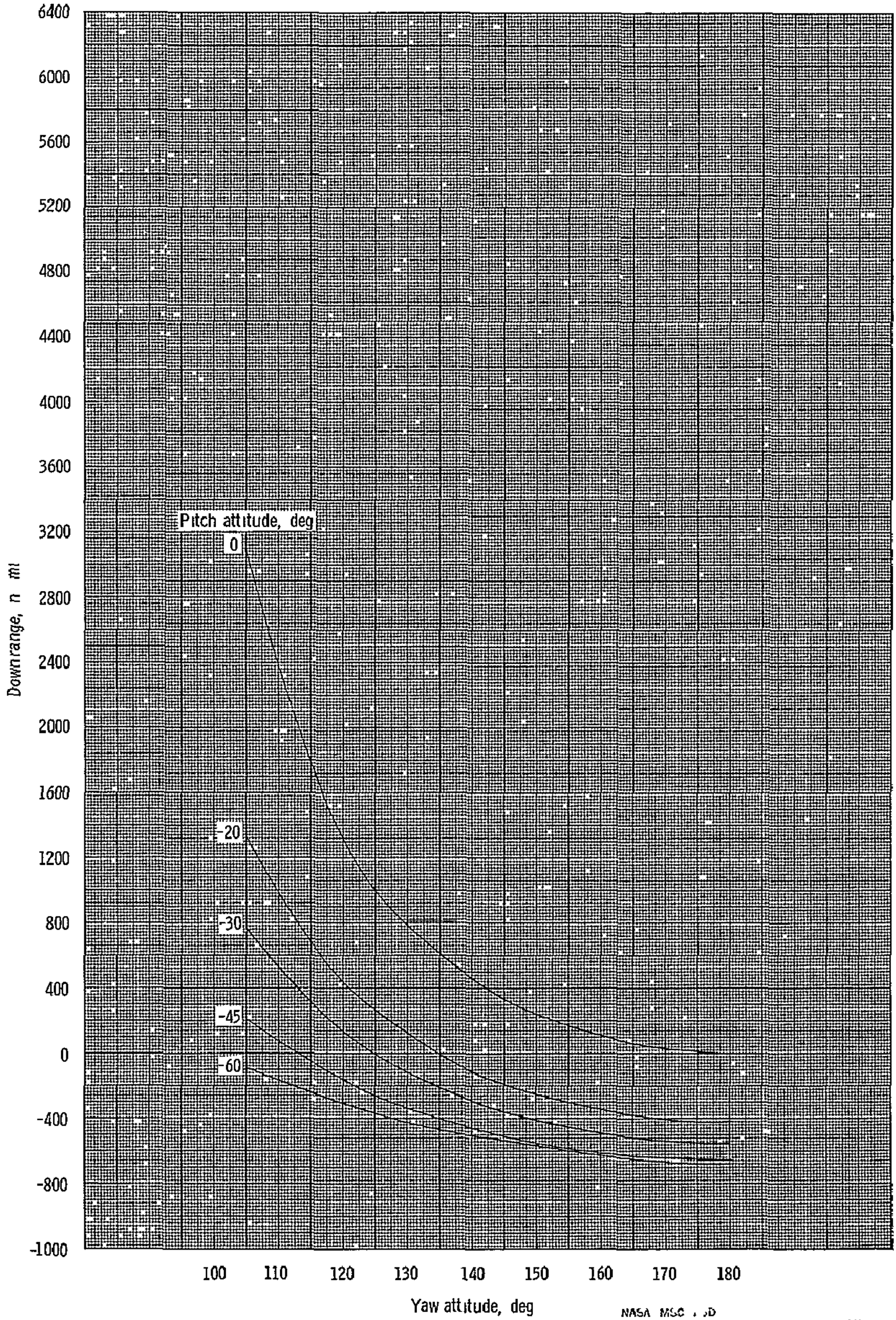
(b) ΔV = 500 fps.

Figure 1. - Continued



(c) ΔV = 600 fps

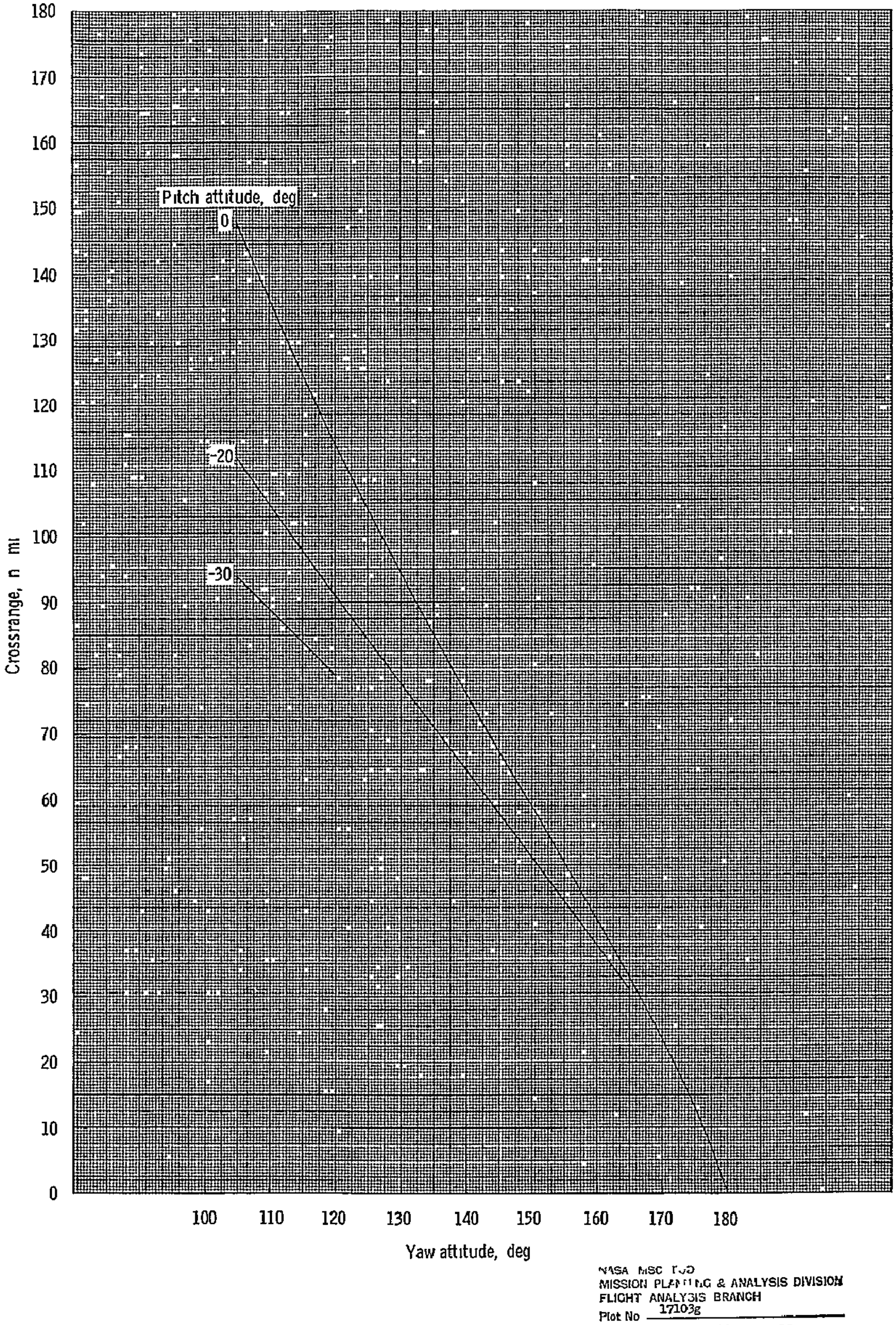
Figure I. - Continued



NASA MSC . .D
MISSION PLANNING & ANALYSIS DIVISION
FLIGHT ANALYSIS BRANCH
Plot No 17103f
Date March 23, 1966 DPS

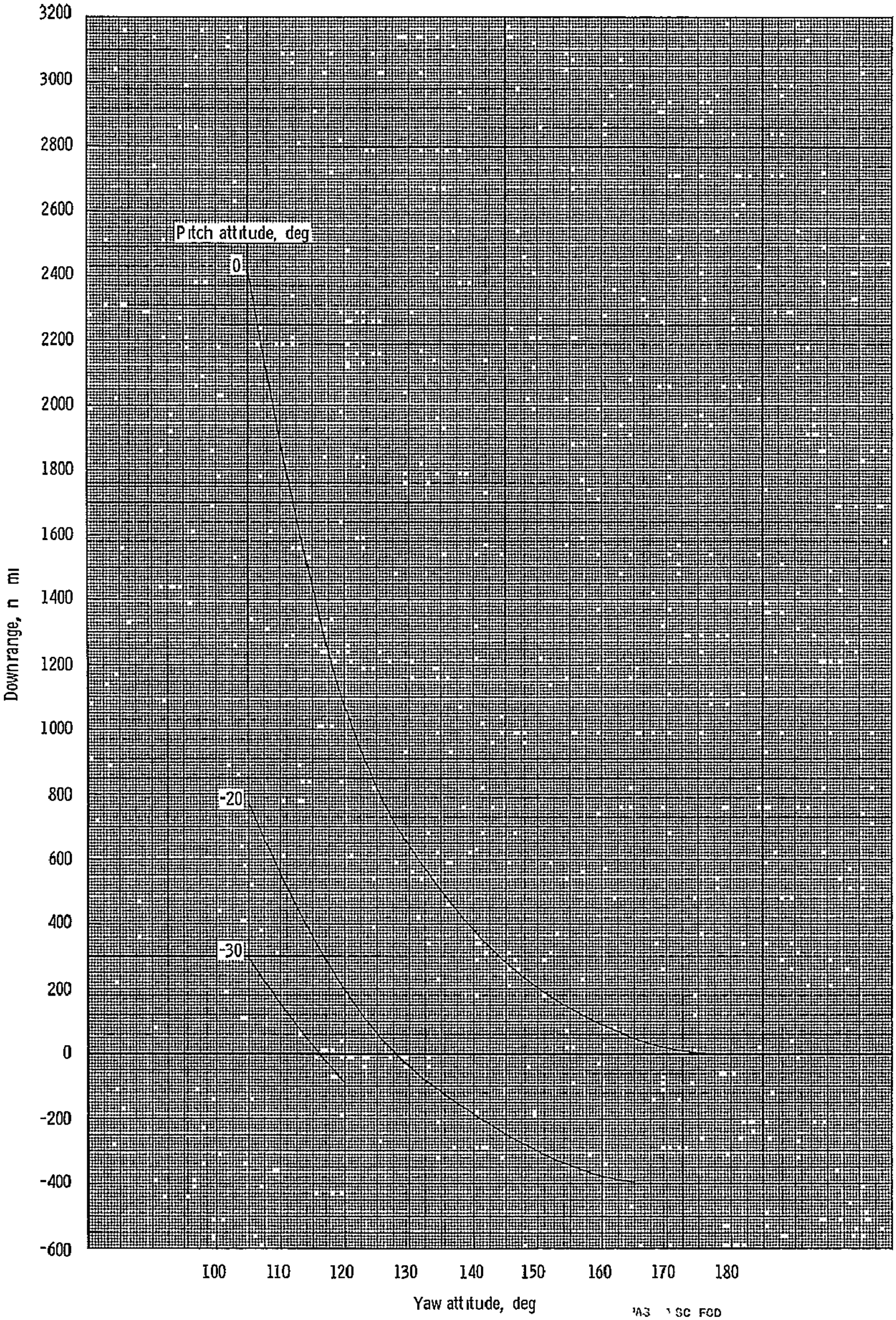
(c) ΔV = 600 fps.

Figure 1. - Continued.



(d) ΔV = 1000 fps

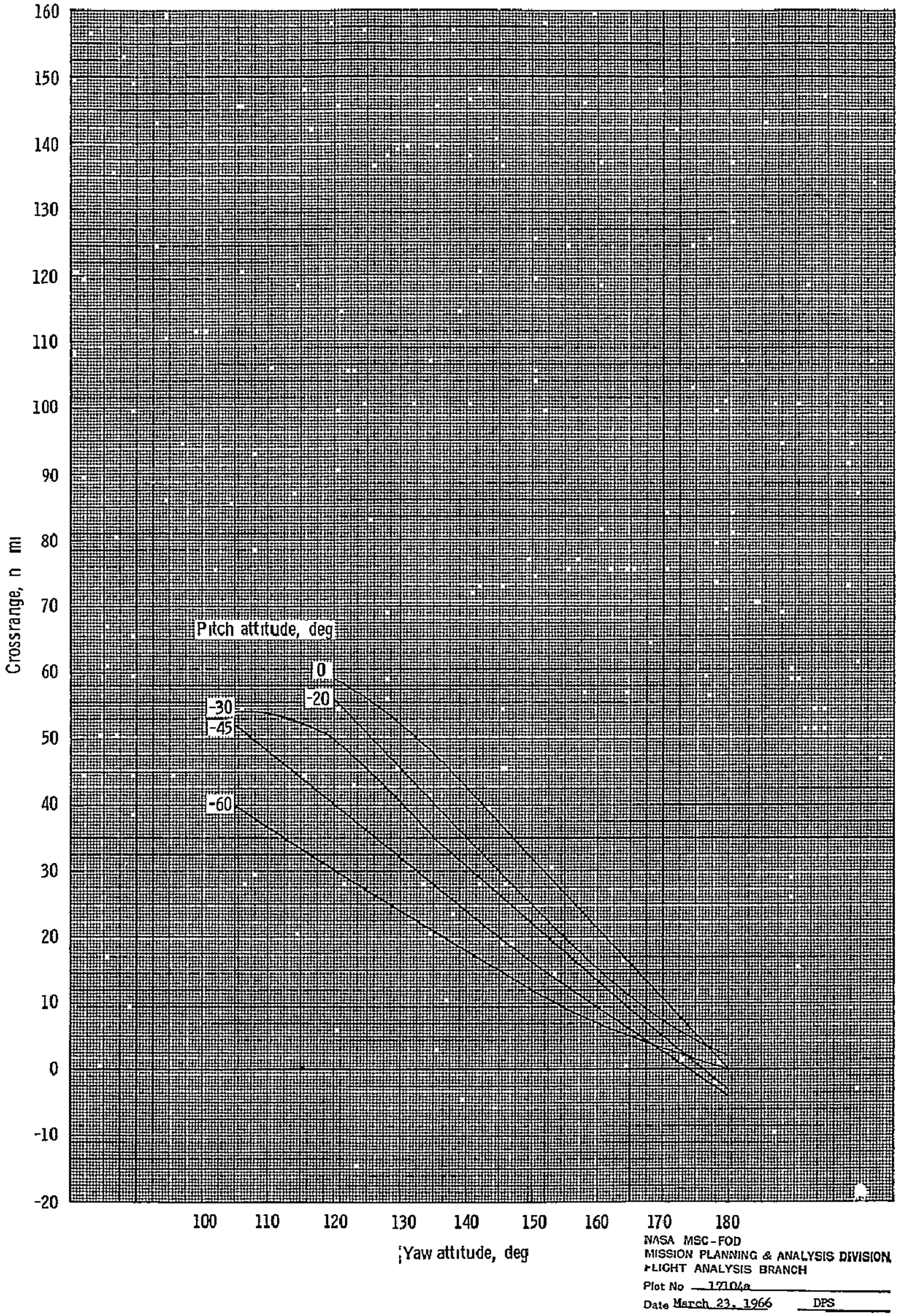
Figure 1. - Continued.



MSC FOD
MISSION PLANNING & ANALYSIS DIVISION
FLIGHT ANALYSIS BRANCH
Plot No 17103h
Date March 23, 1966 DPS

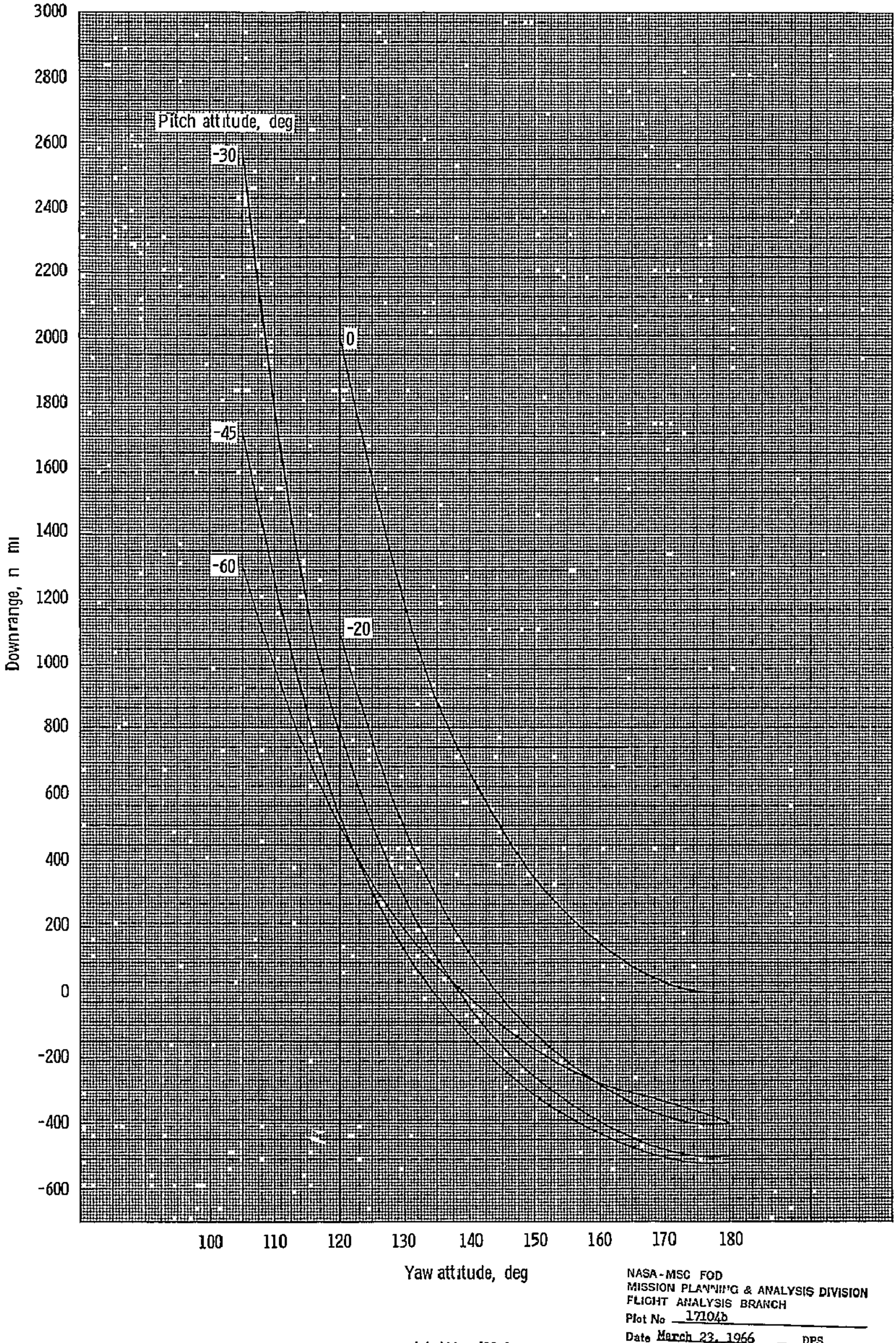
(d) ΔV = 1000 fps.

Figure 1. - Concluded.



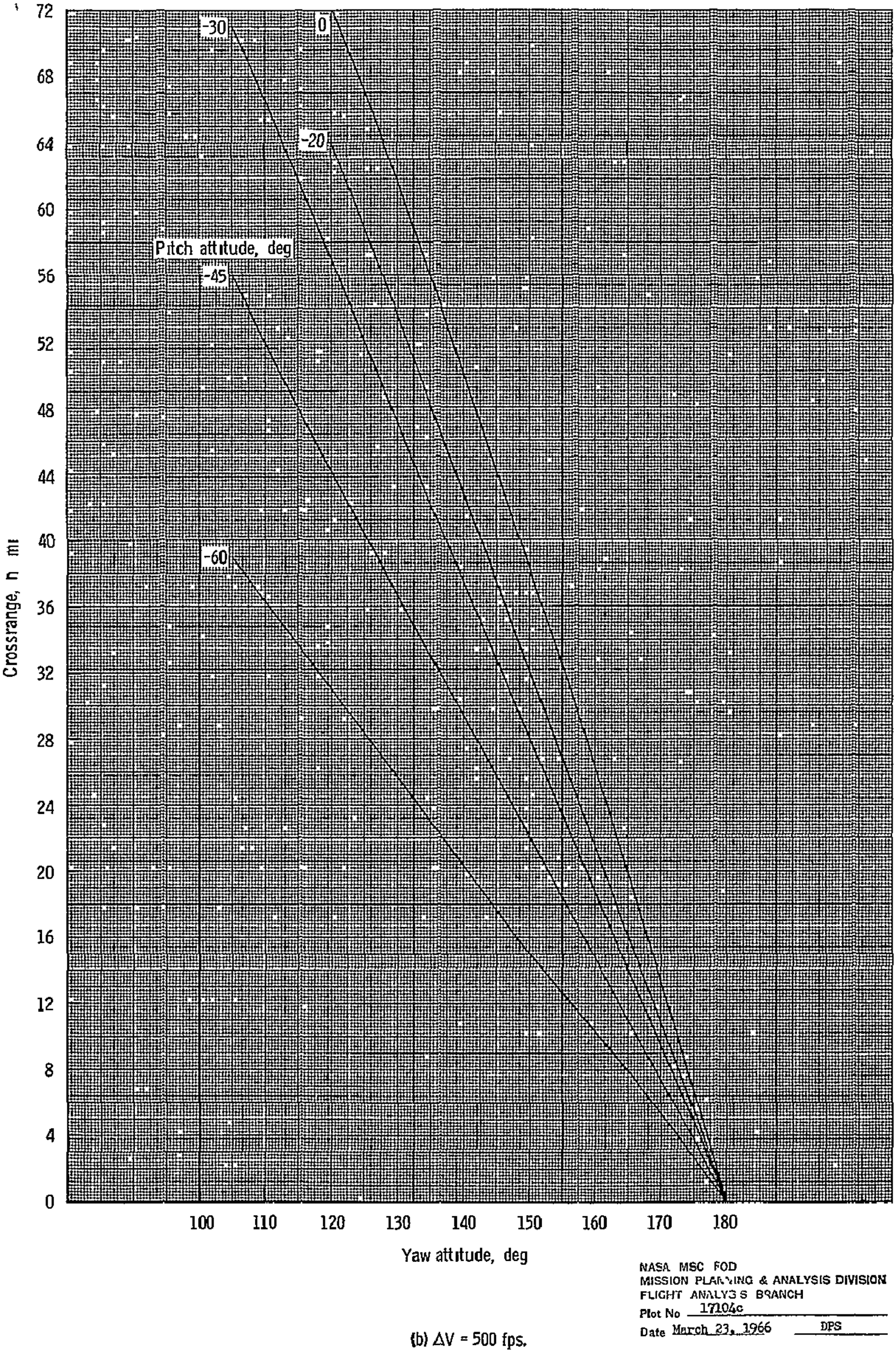
(a) ΔV = 400 fps

Figure 2. - 100 nautical mile circular orbit for various burn attitudes with downrange or crossrange versus yaw attitude for various pitches



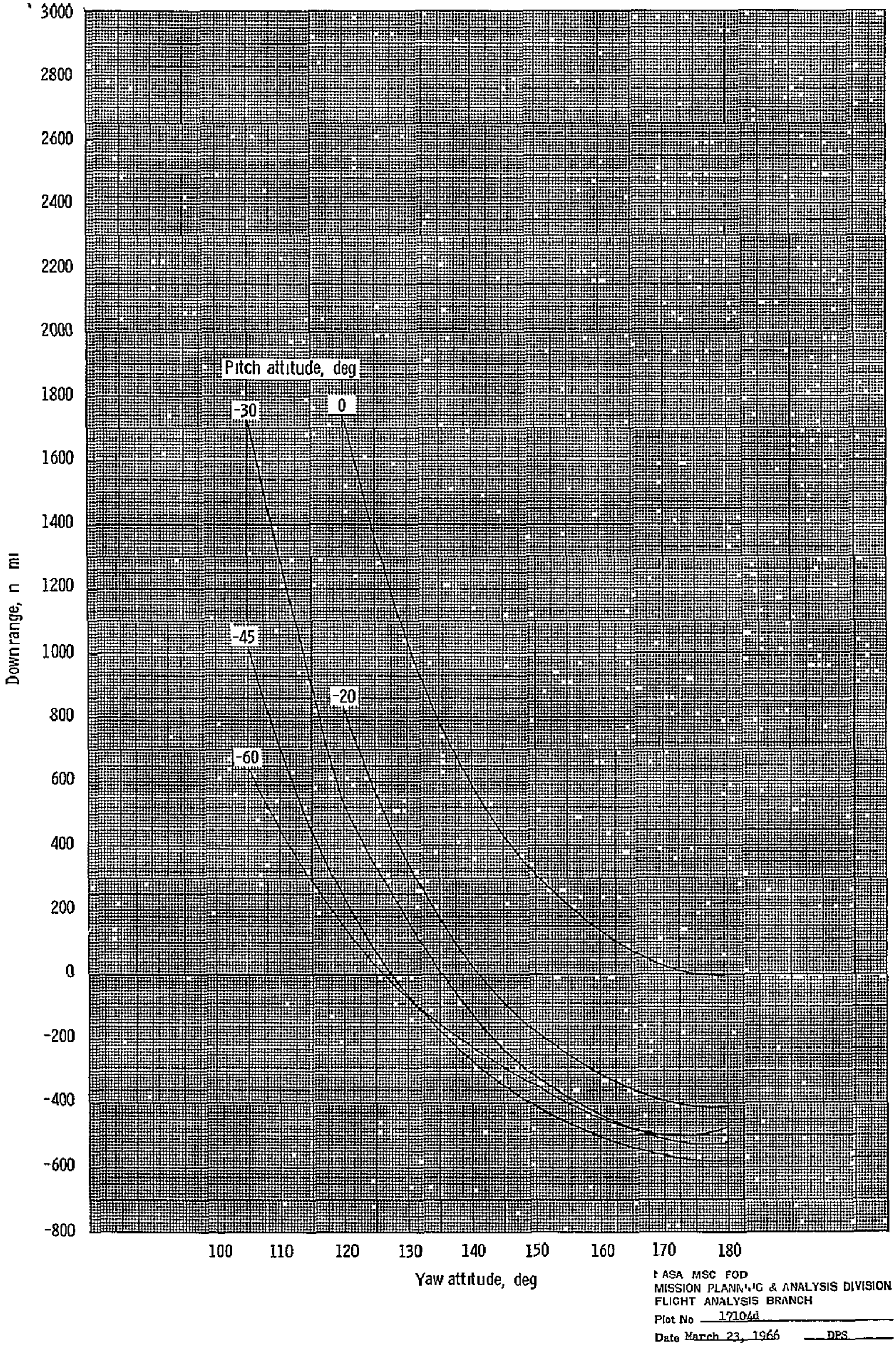
(a) ΔV = 400 fps

Figure 2. - Continued.



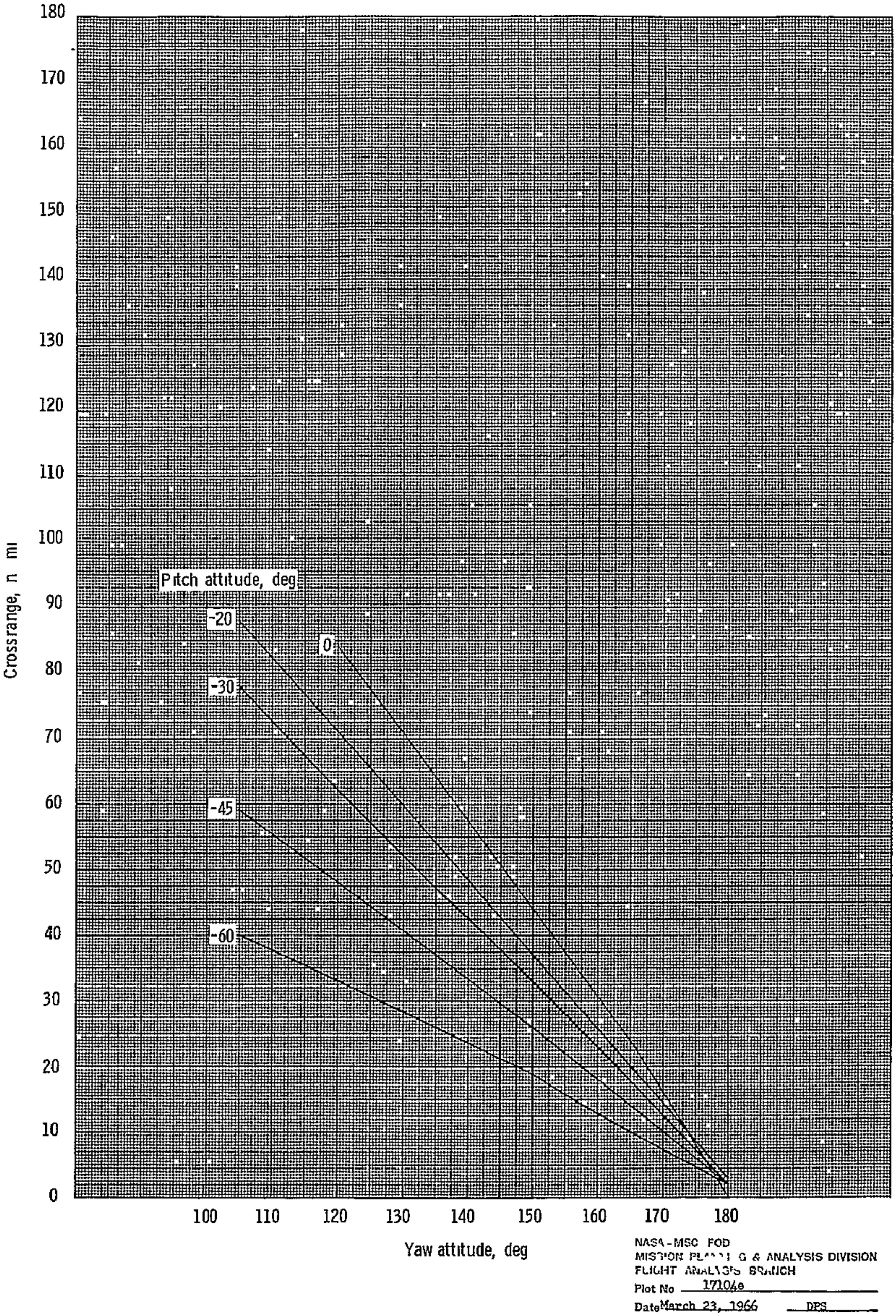
(b) ΔV = 500 fps.

Figure 2. - Continued.



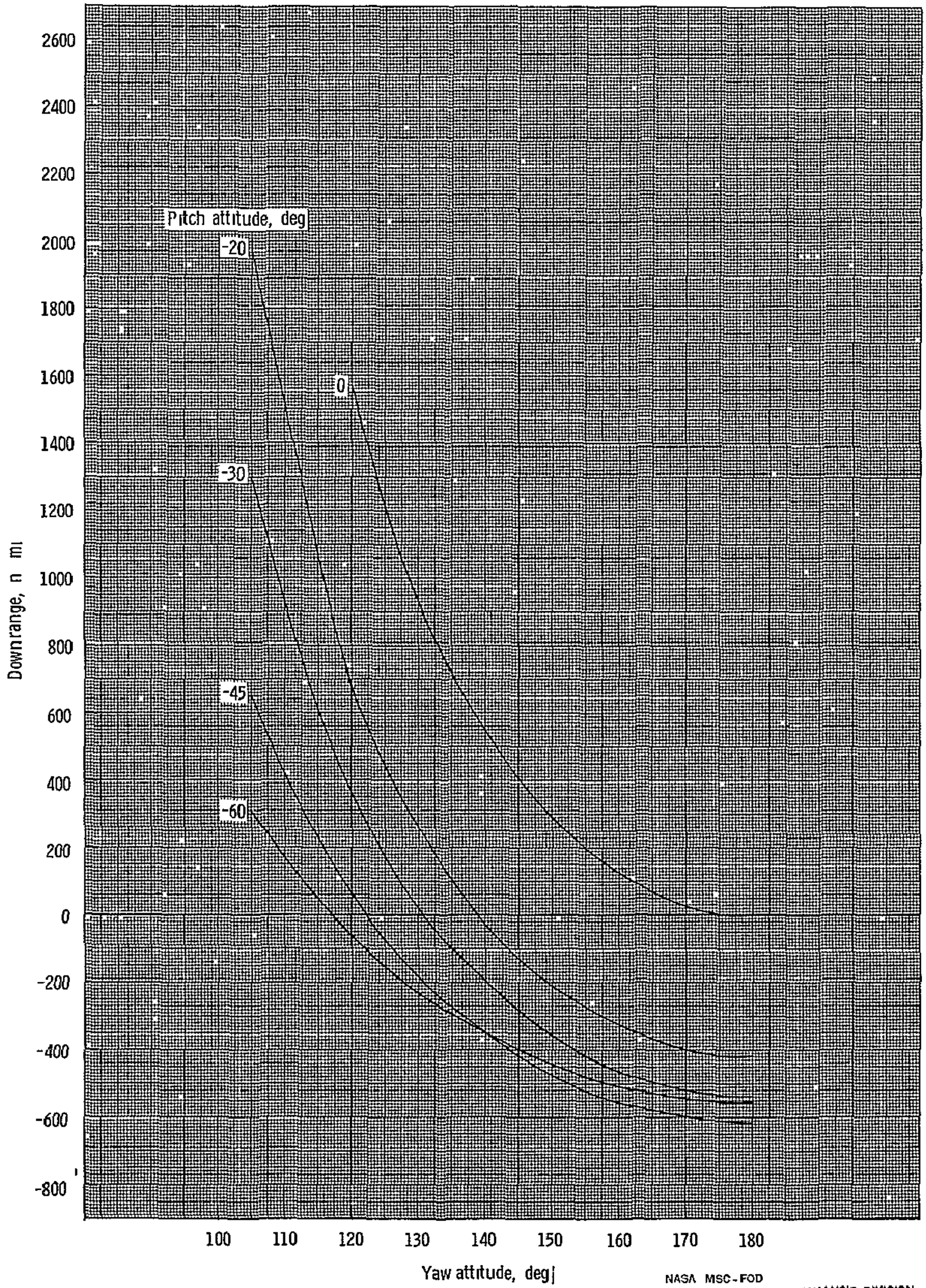
(b) ΔV = 500 fps

Figure 2. - Continued.



(c) ΔV = 600 fps.

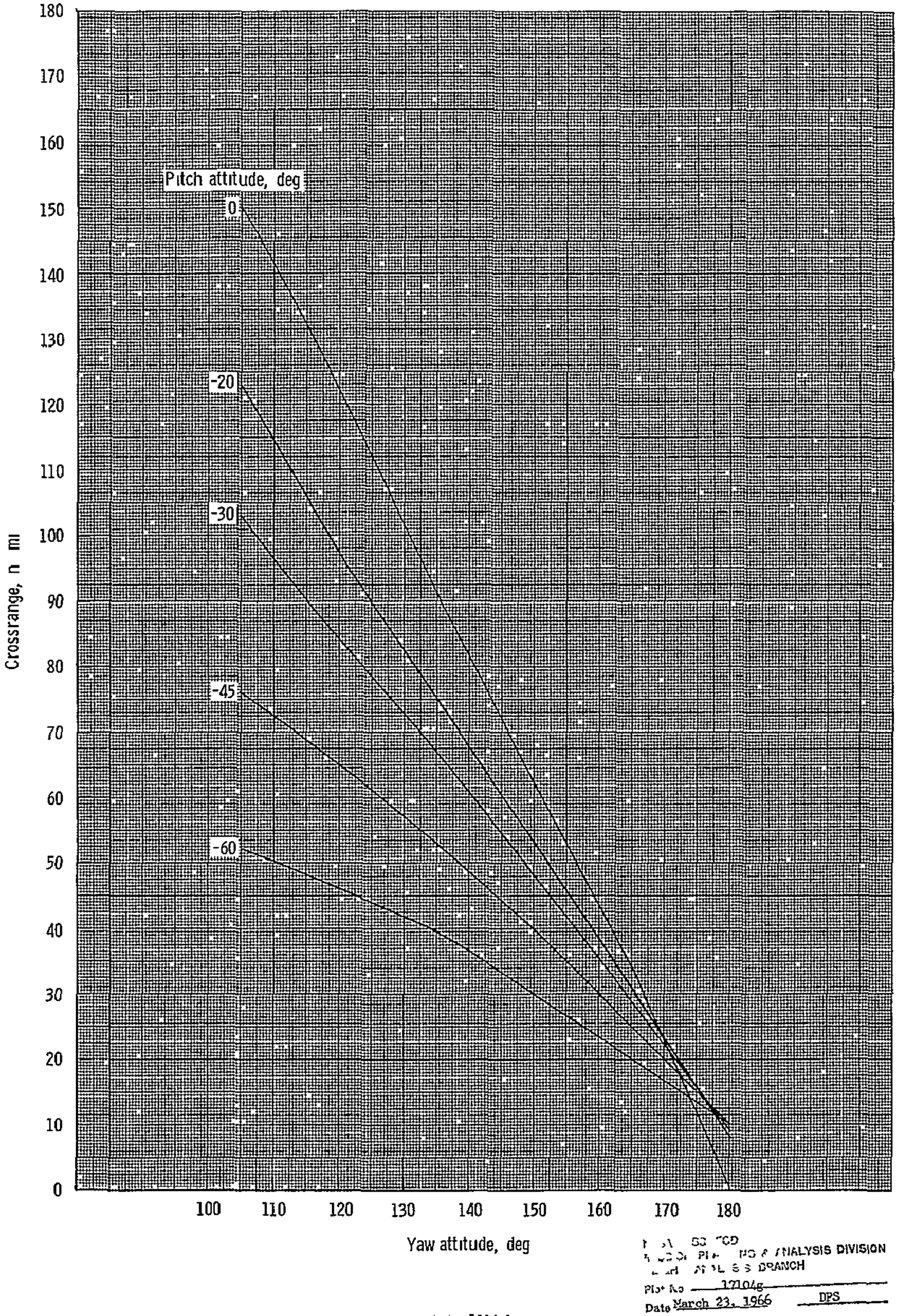
Figure 2 - Continued.



NASA MSC-FOD
MISSION PLANNING & ANALYSIS DIVISION
FLIGHT ANALYSIS BRANCH
Plot No 17104f
Date March 23, 1966 DPS

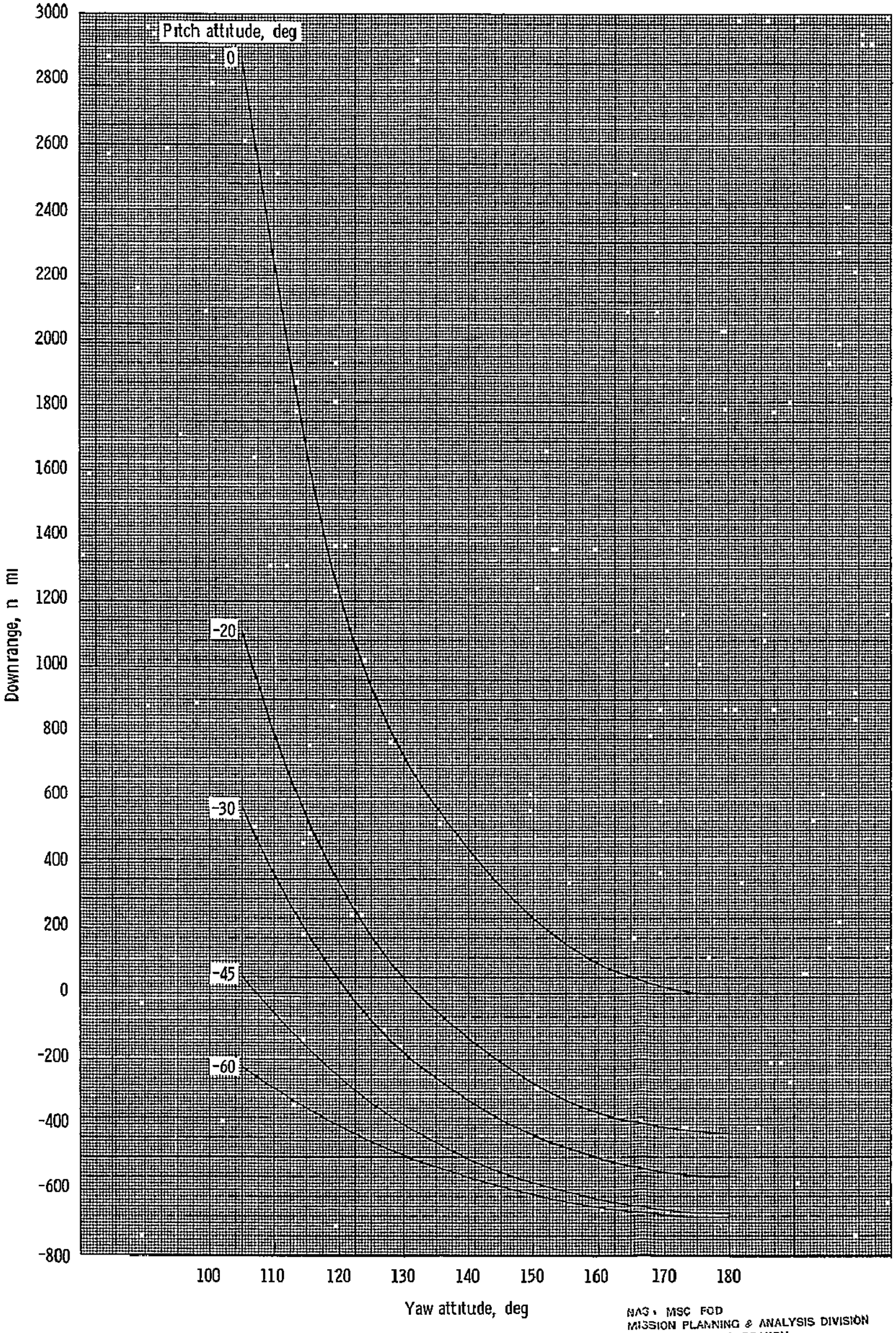
(c) ΔV = 600 fps

Figure 2. - Continued.



(d) ΔV = 1000 fps

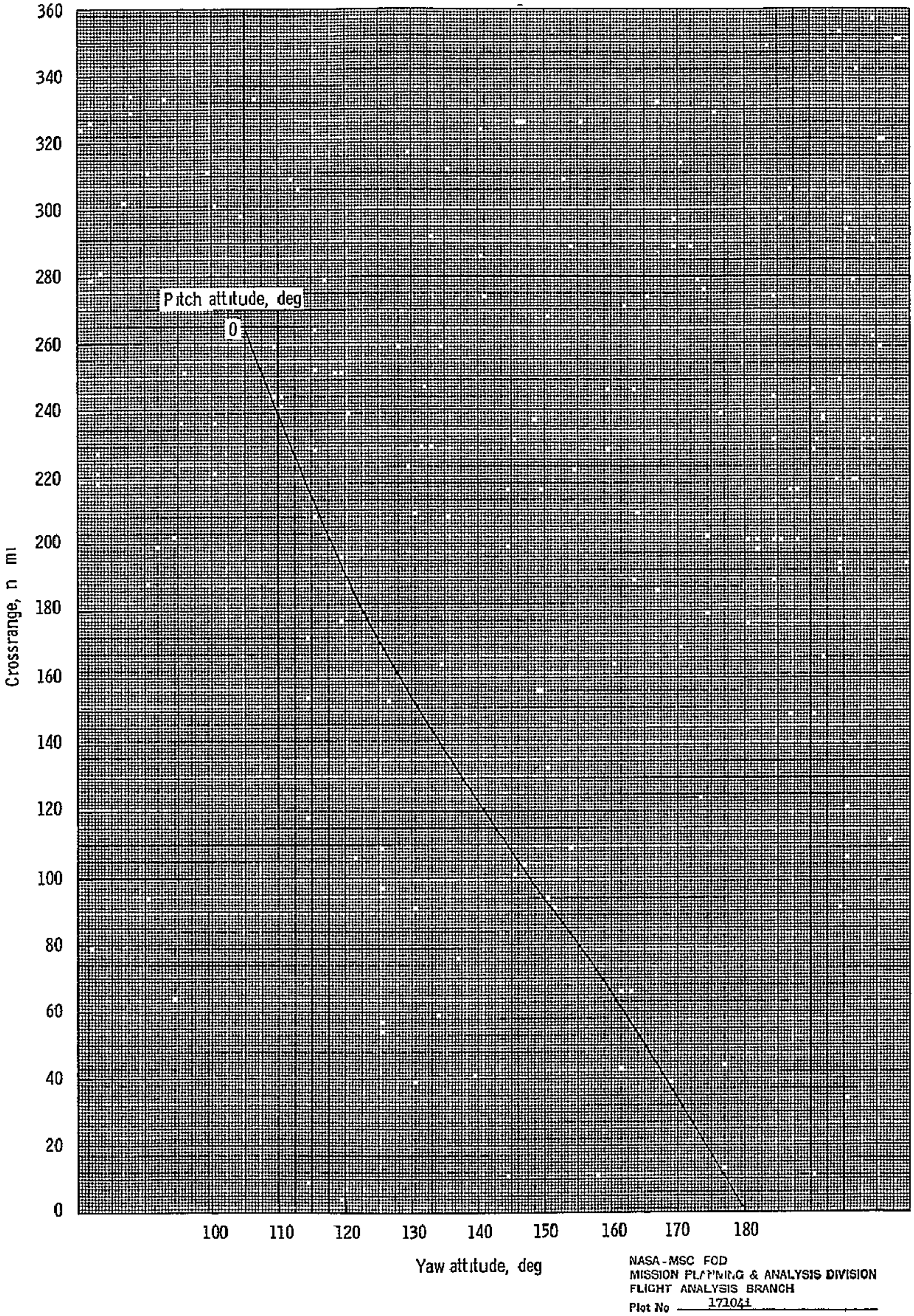
Figure 2. - Continued.



NASA MSC FOD
MISSION PLANNING & ANALYSIS DIVISION
FLIGHT ANALYSIS BRANCH
Plot No 17104h
Date March 23, 1966 DPS

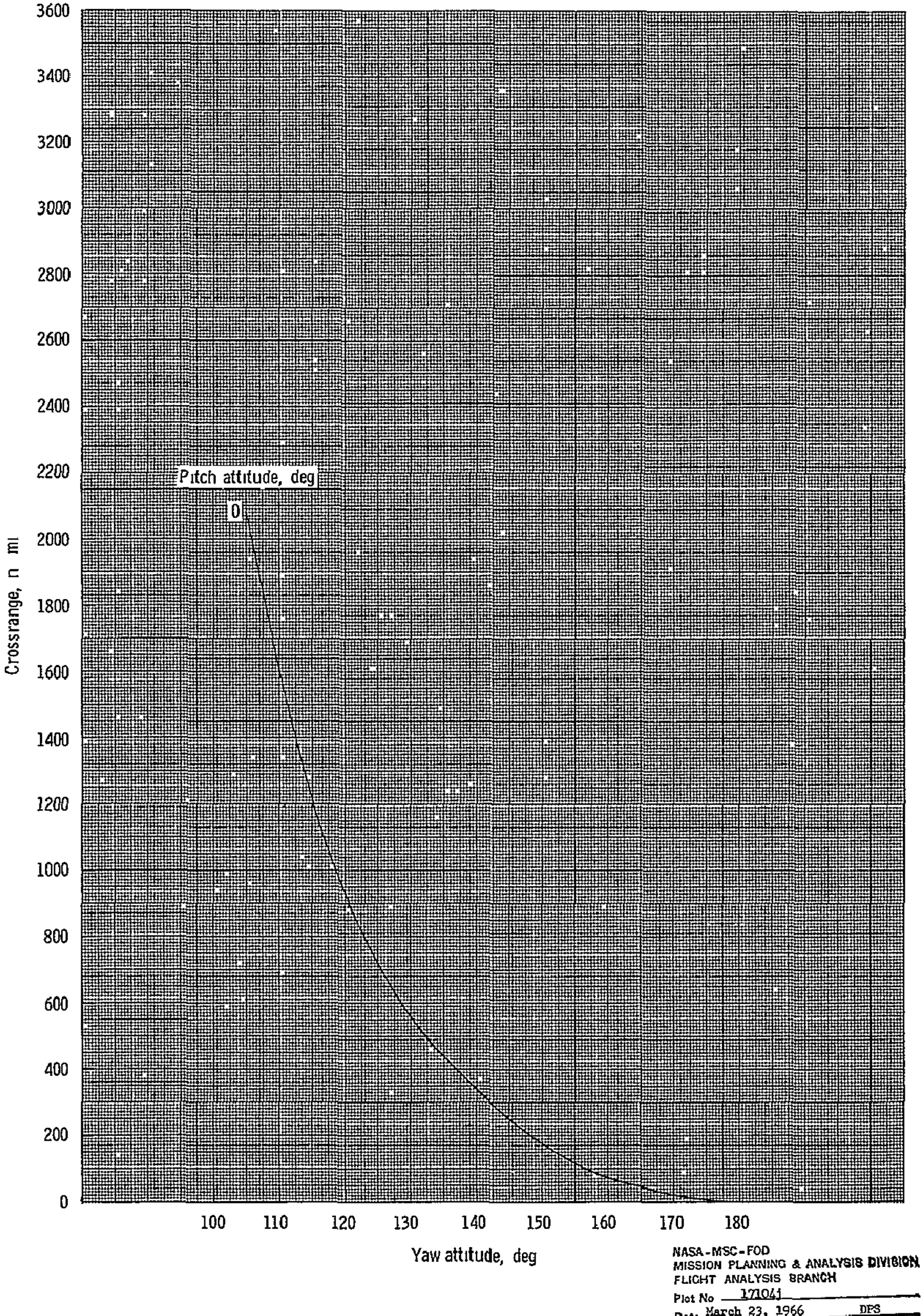
(d) ΔV = 1000 fps.

Figure 2. - Continued



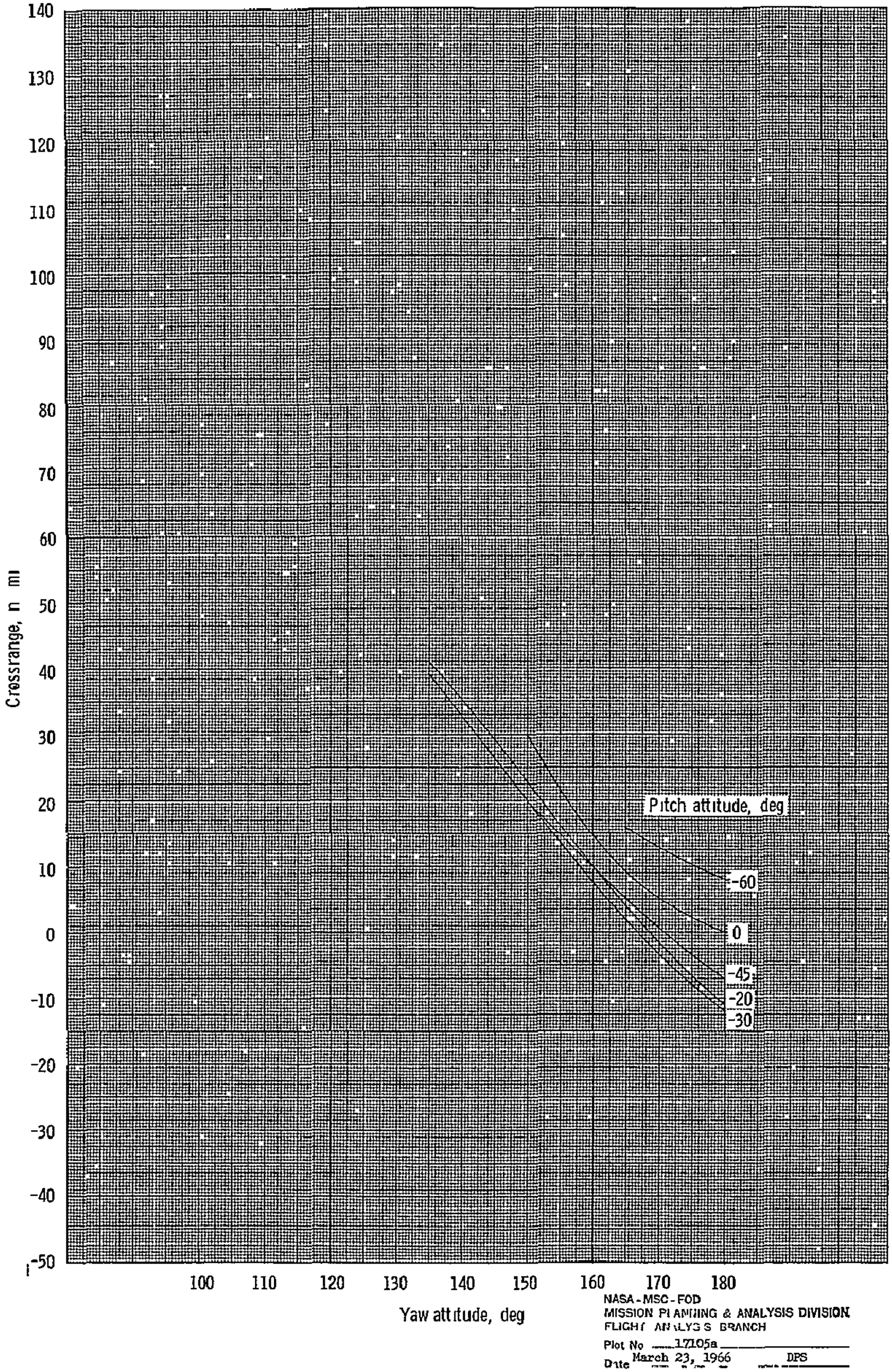
(e) ΔV = 2000 fps.

Figure 2. - Continued.



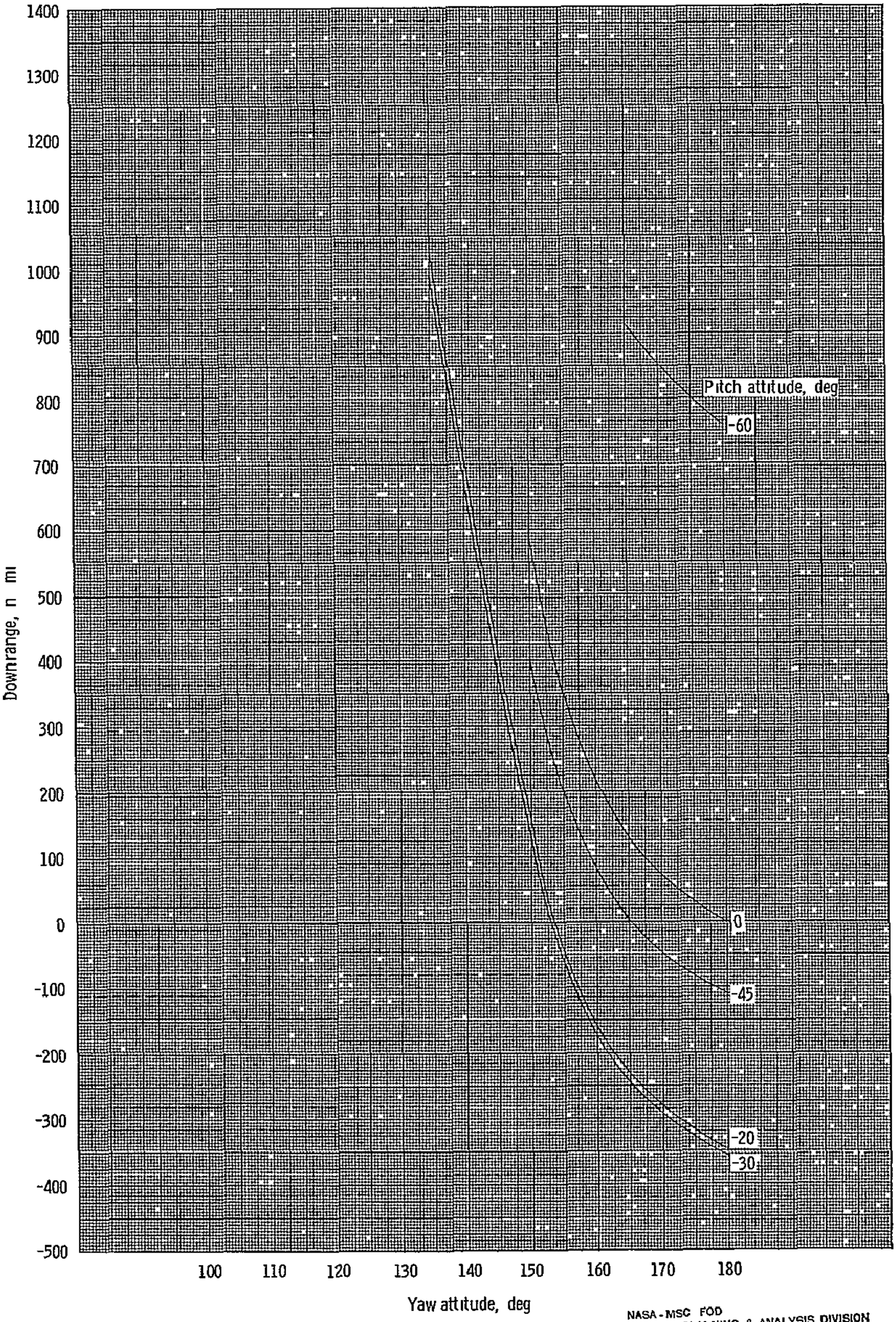
(e) ΔV = 2000 fps.

Figure 2. - Concluded.



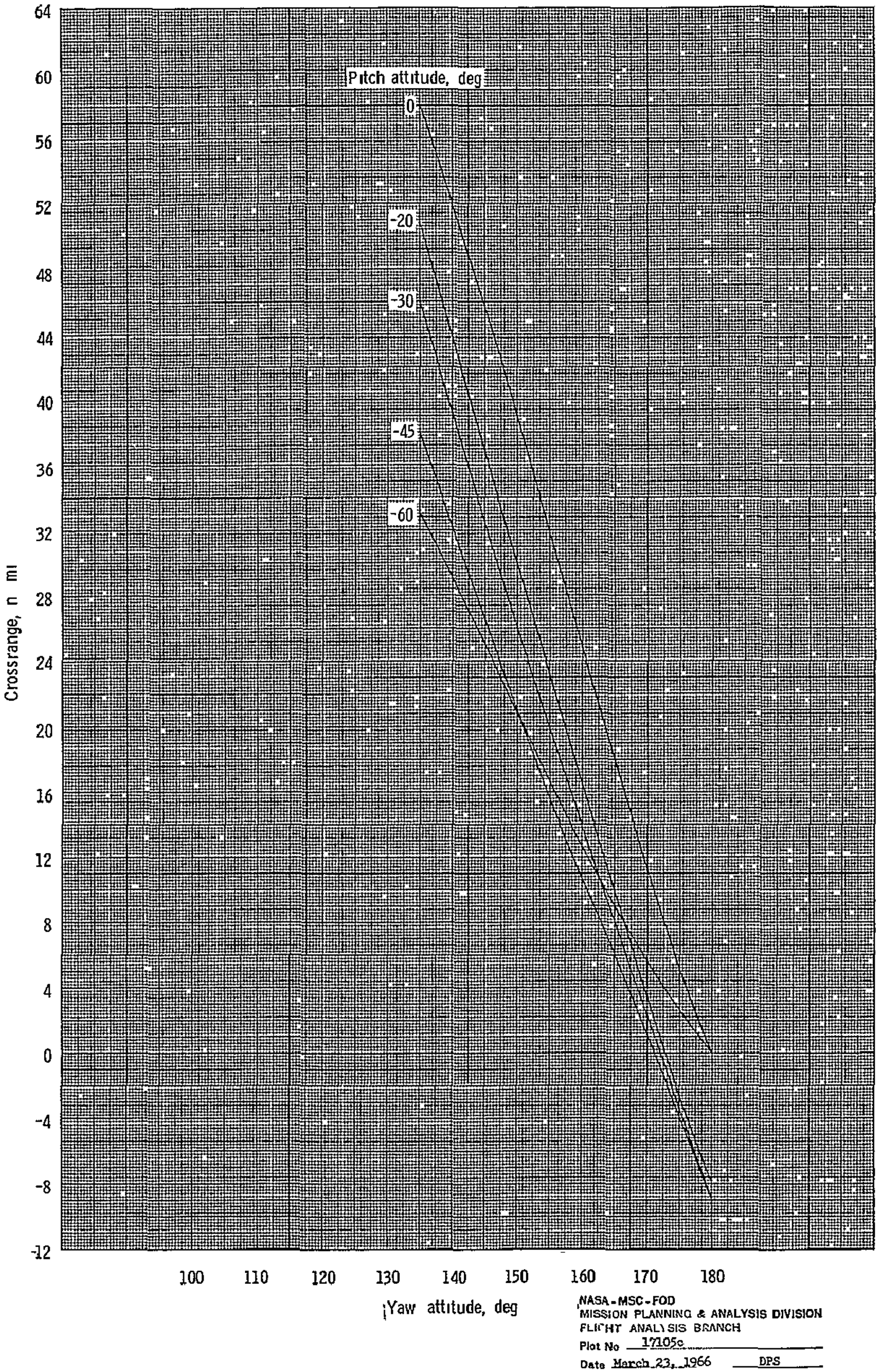
(a) ΔV = 400 fps

Figure 3 - 150 nautical mile circular orbit for various burn attitudes with downrange or crossrange versus yaw attitude for various pitches



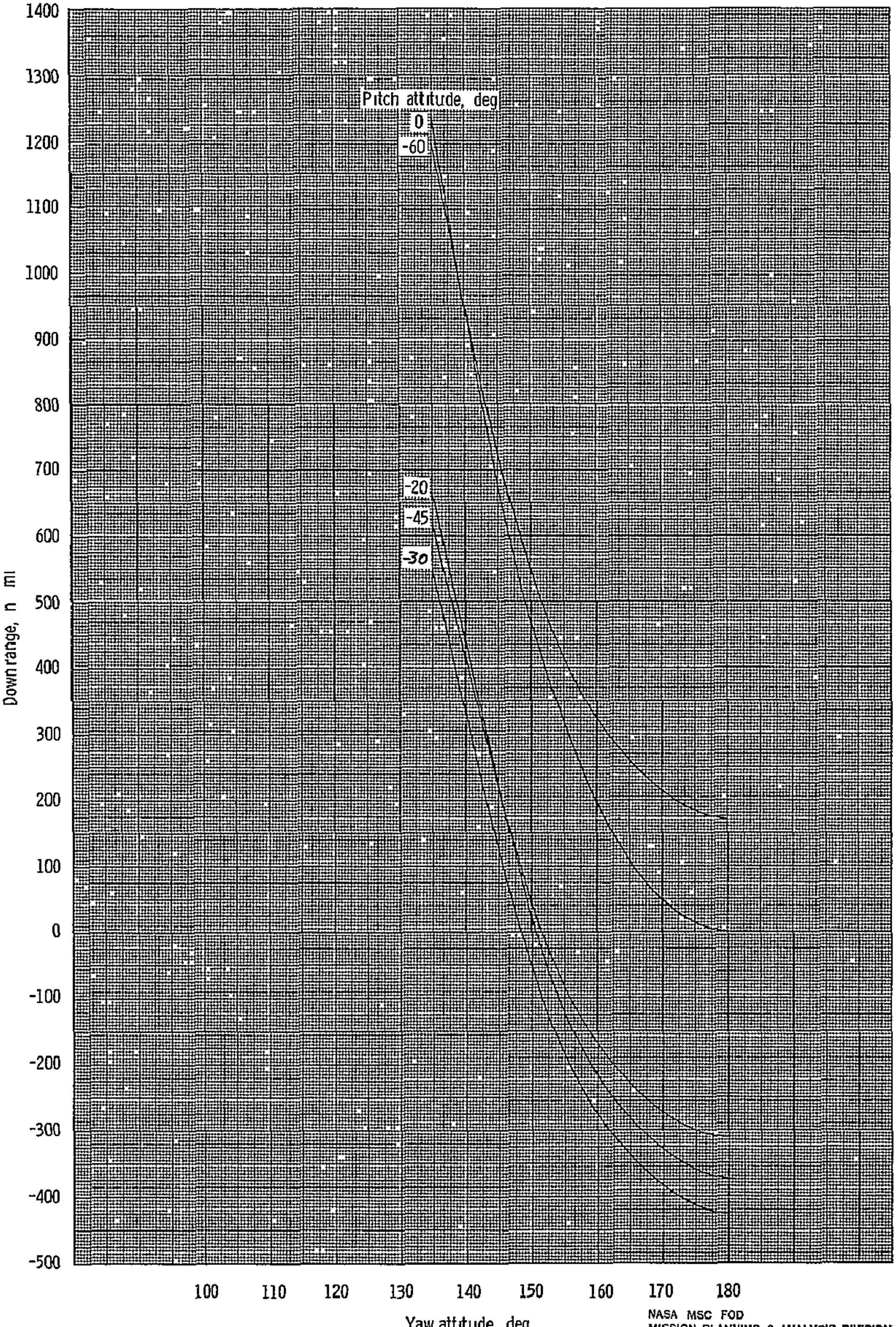
(a) ΔV = 400 fps

Figure 3. - Continued



(b) ΔV = 500 fps

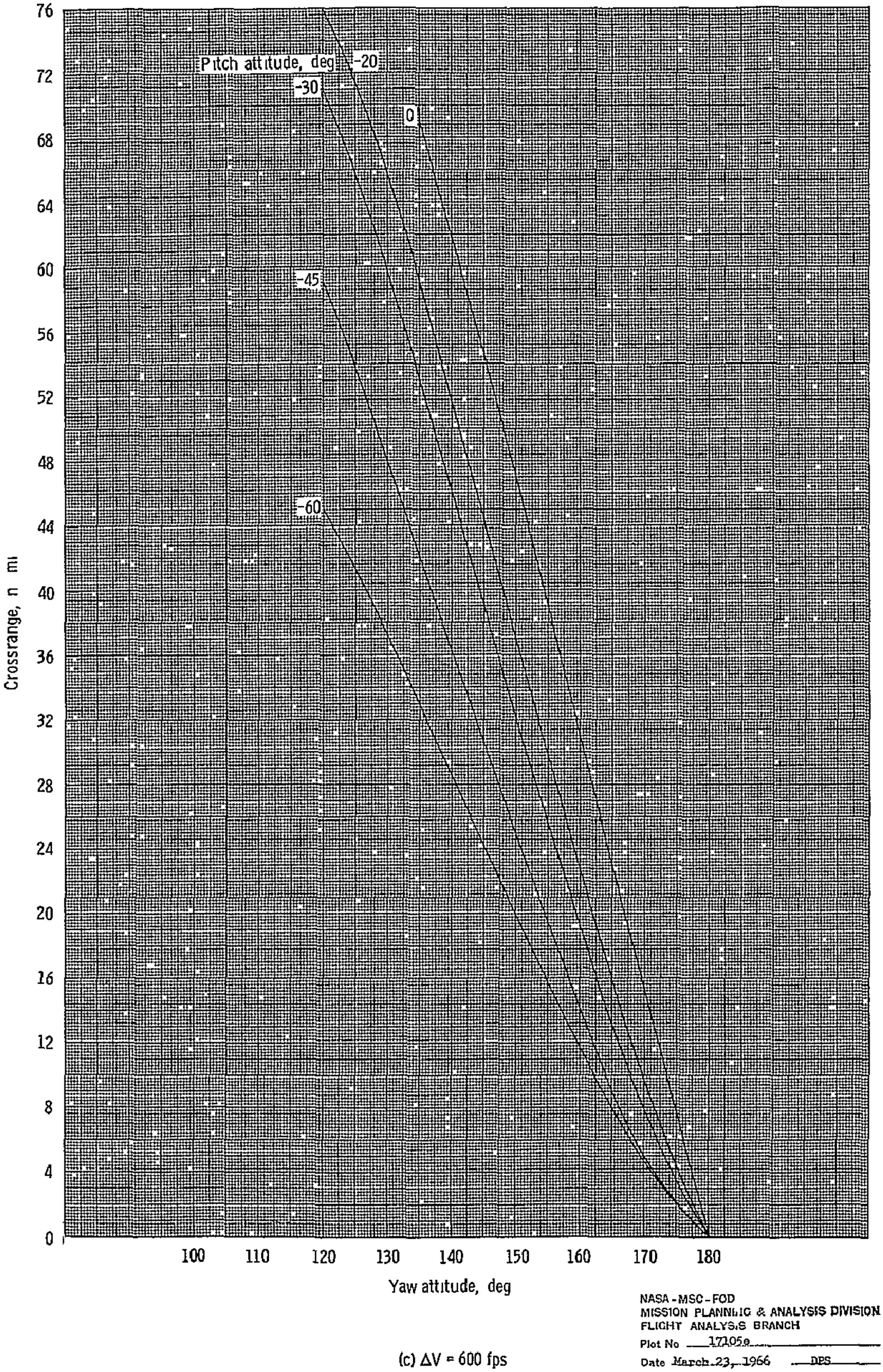
Figure 3 - Continued



NASA MSC FOD
MISSION PLANNING & ANALYSIS DIVISION
FLIGHT ANALYSIS BRANCH
Plot No 17105d
Date March 23, 1966

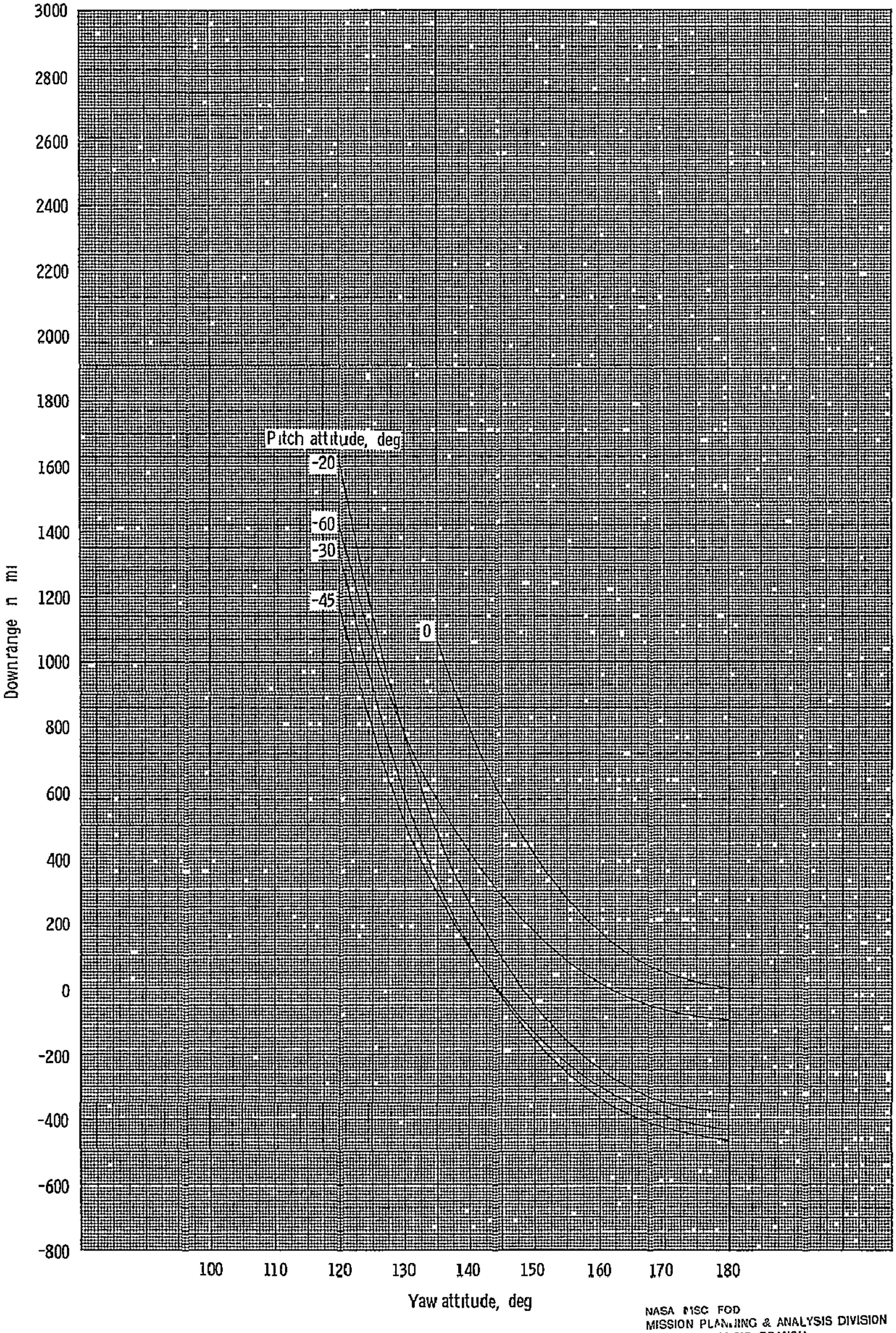
(b) ΔV = 500 fps.

Figure 3. - Continued.



(c) ΔV = 600 fps

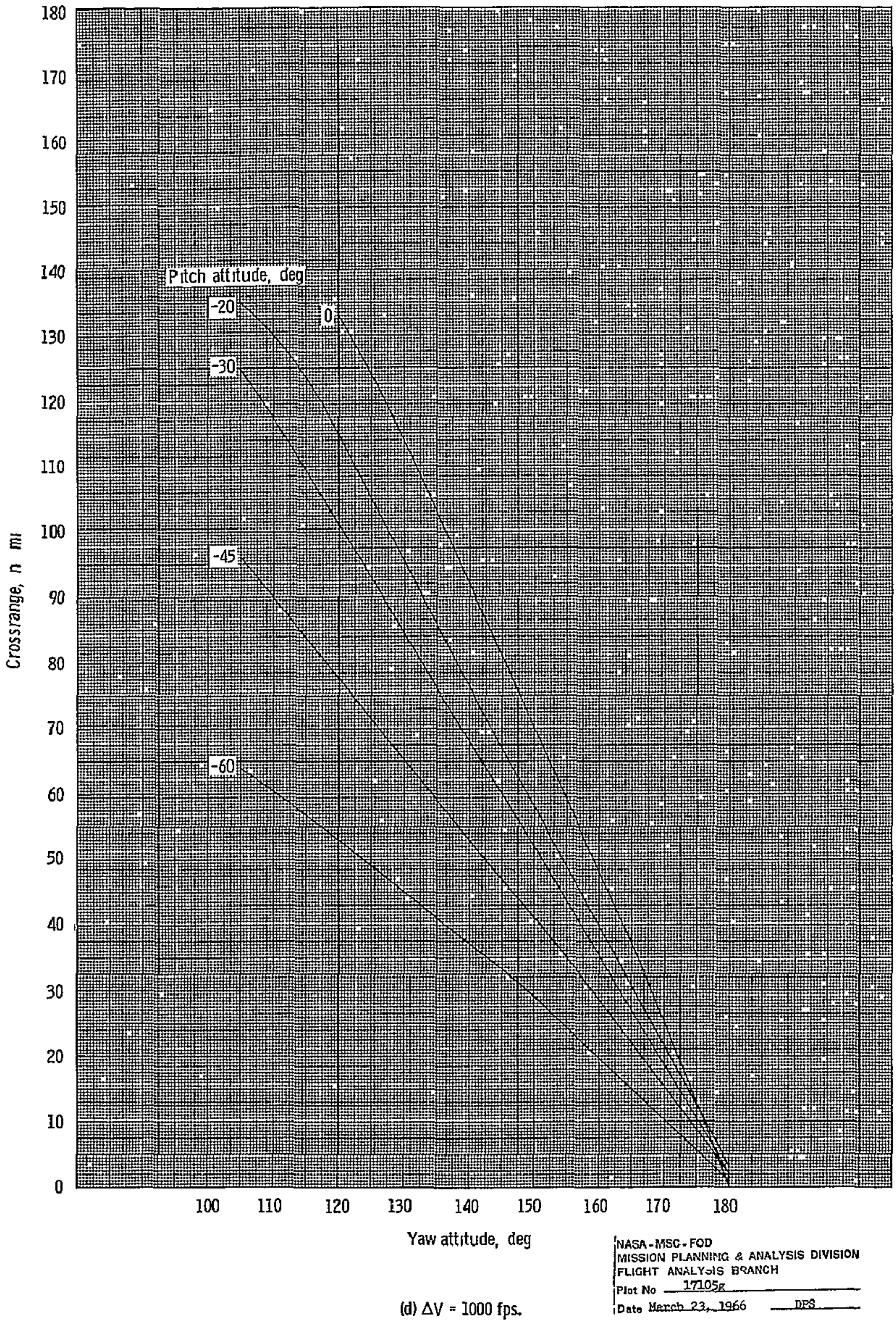
Figure 3 - Continued



NASA MSC FOD
MISSION PLANNING & ANALYSIS DIVISION
FLIGHT ANALYSIS BRANCH
Plot No 17105f
Date March 23, 1966 DPS

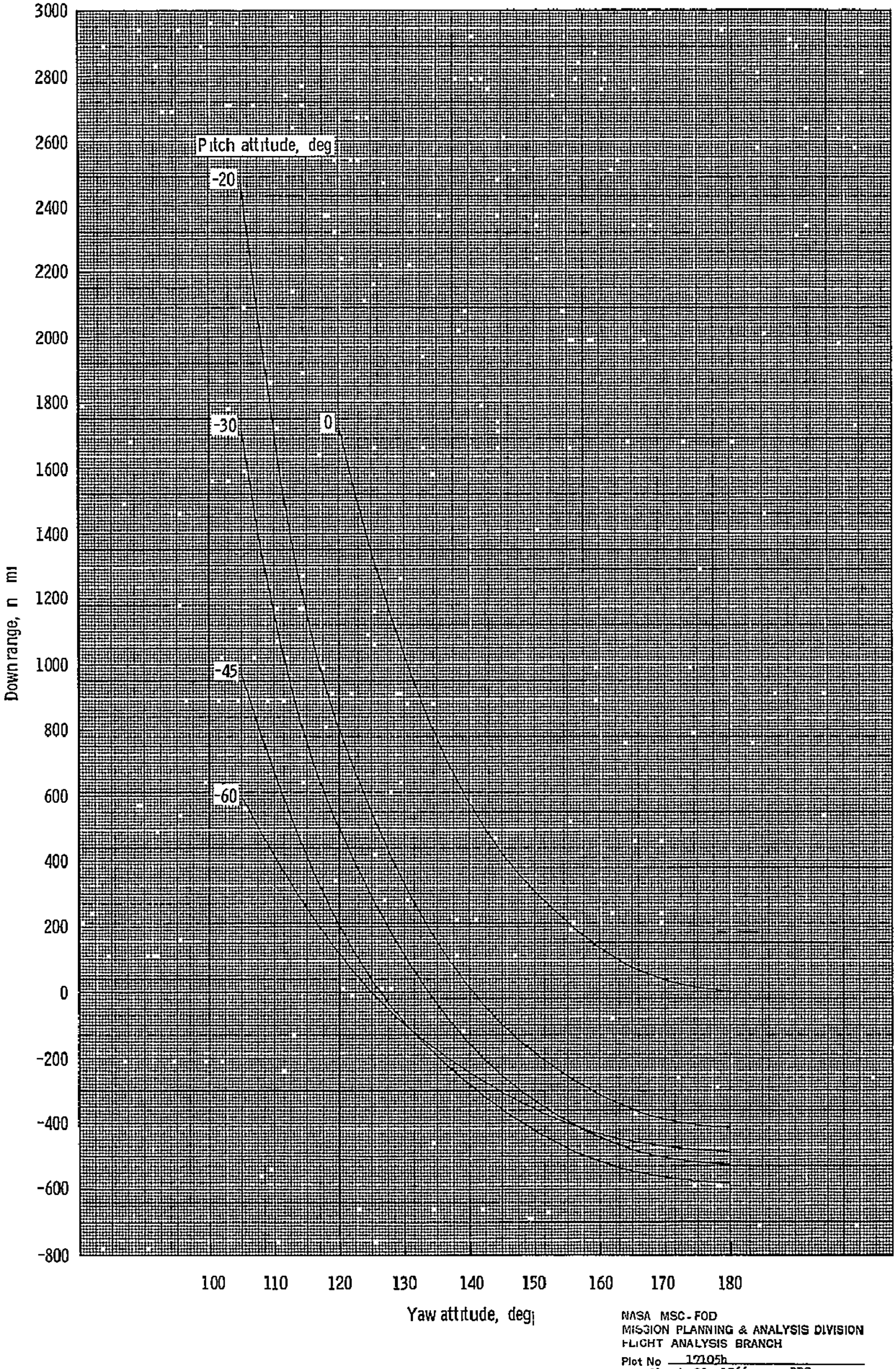
(c) ΔV = 600 fps.

Figure 3 - Continued



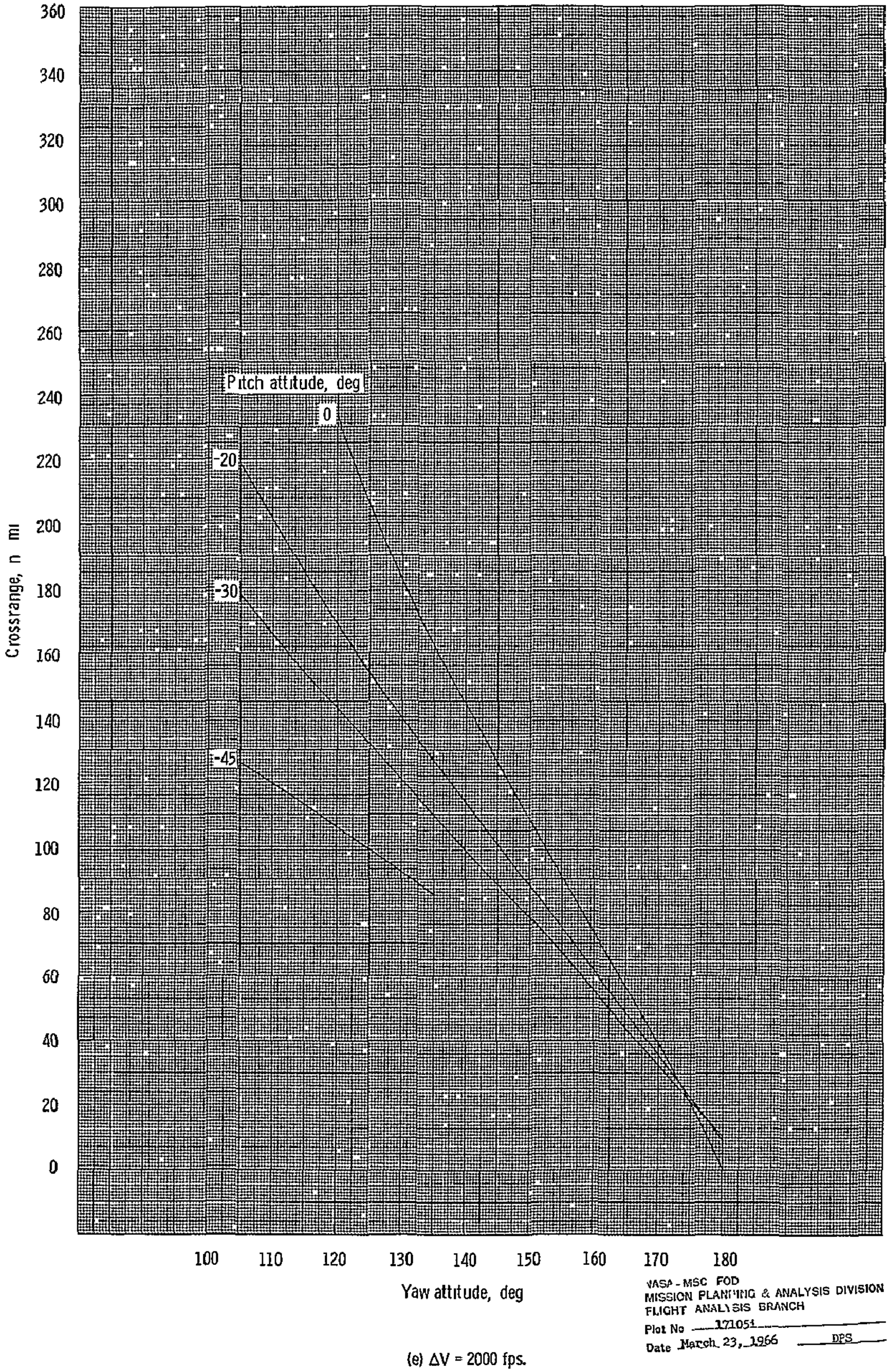
(d) ΔV = 1000 fps.

Figure 3 - Continued.



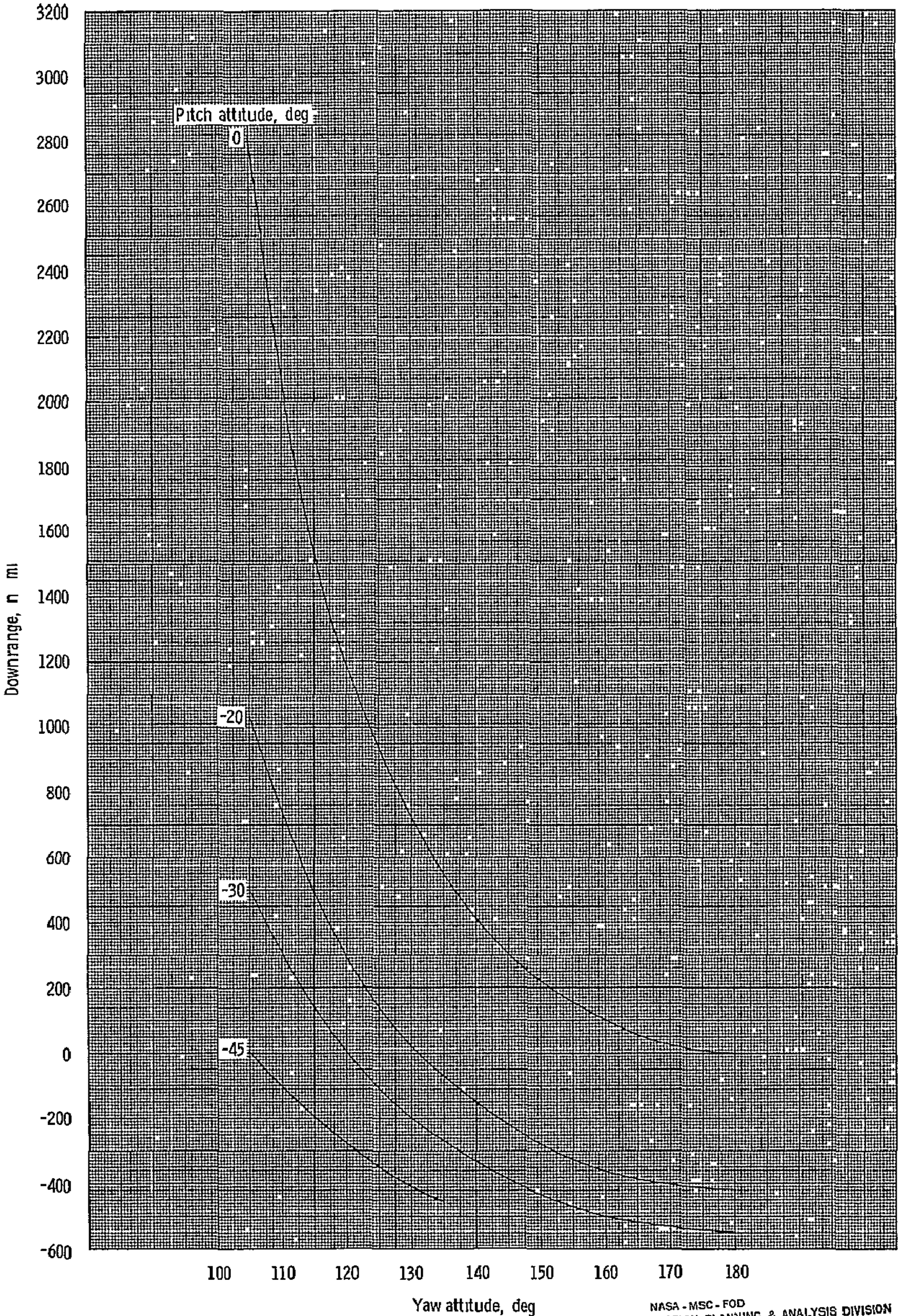
(d) ΔV = 1000 fps.

Figure 3 - Continued.



(e) ΔV = 2000 fps.

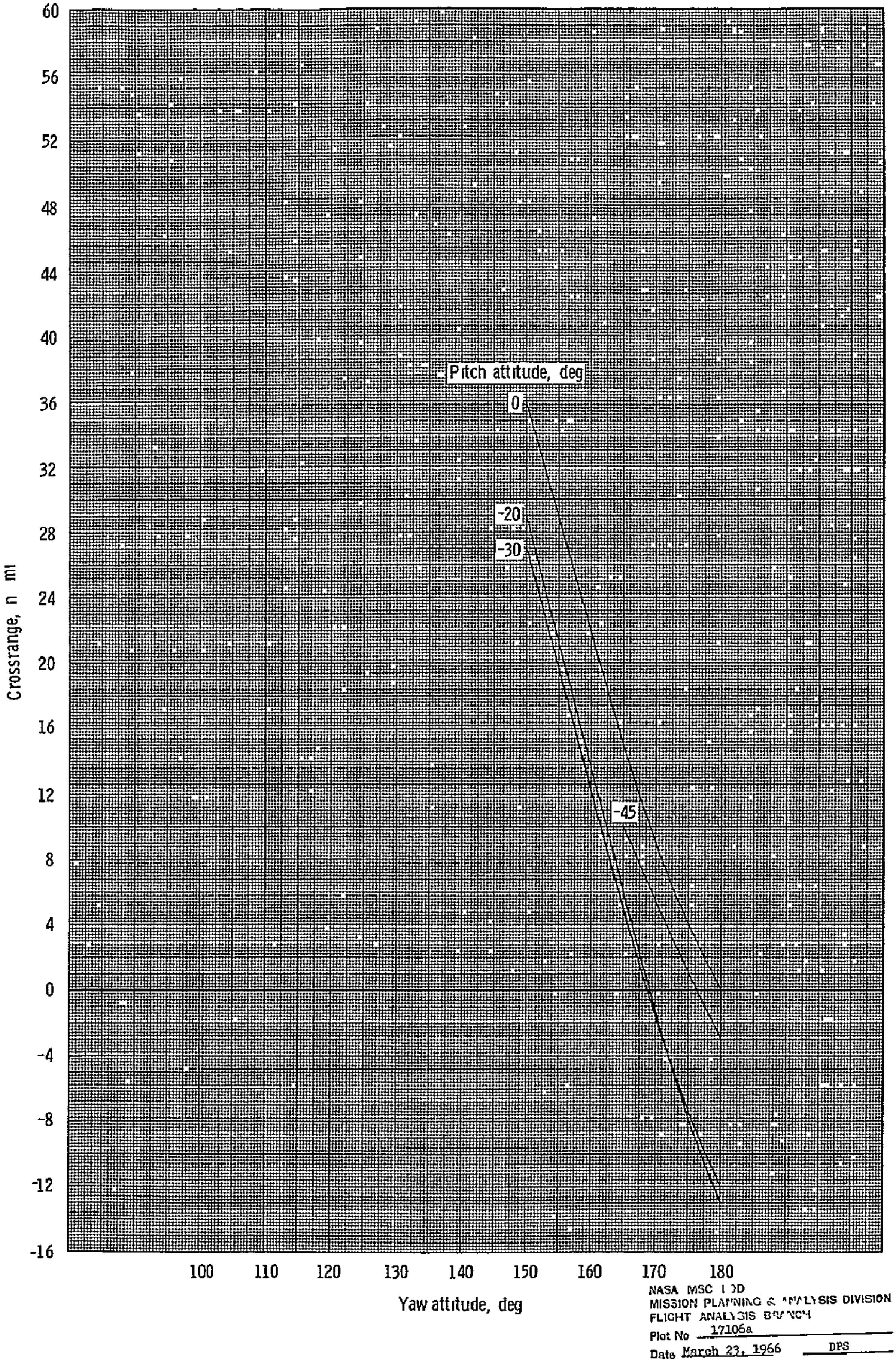
Figure 3 - Continued



NASA - MSC - FOD
MISSION PLANNING & ANALYSIS DIVISION
FLIGHT ANALYSIS BRANCH
Plot No 17105j
Date March 23, 1966 DPS

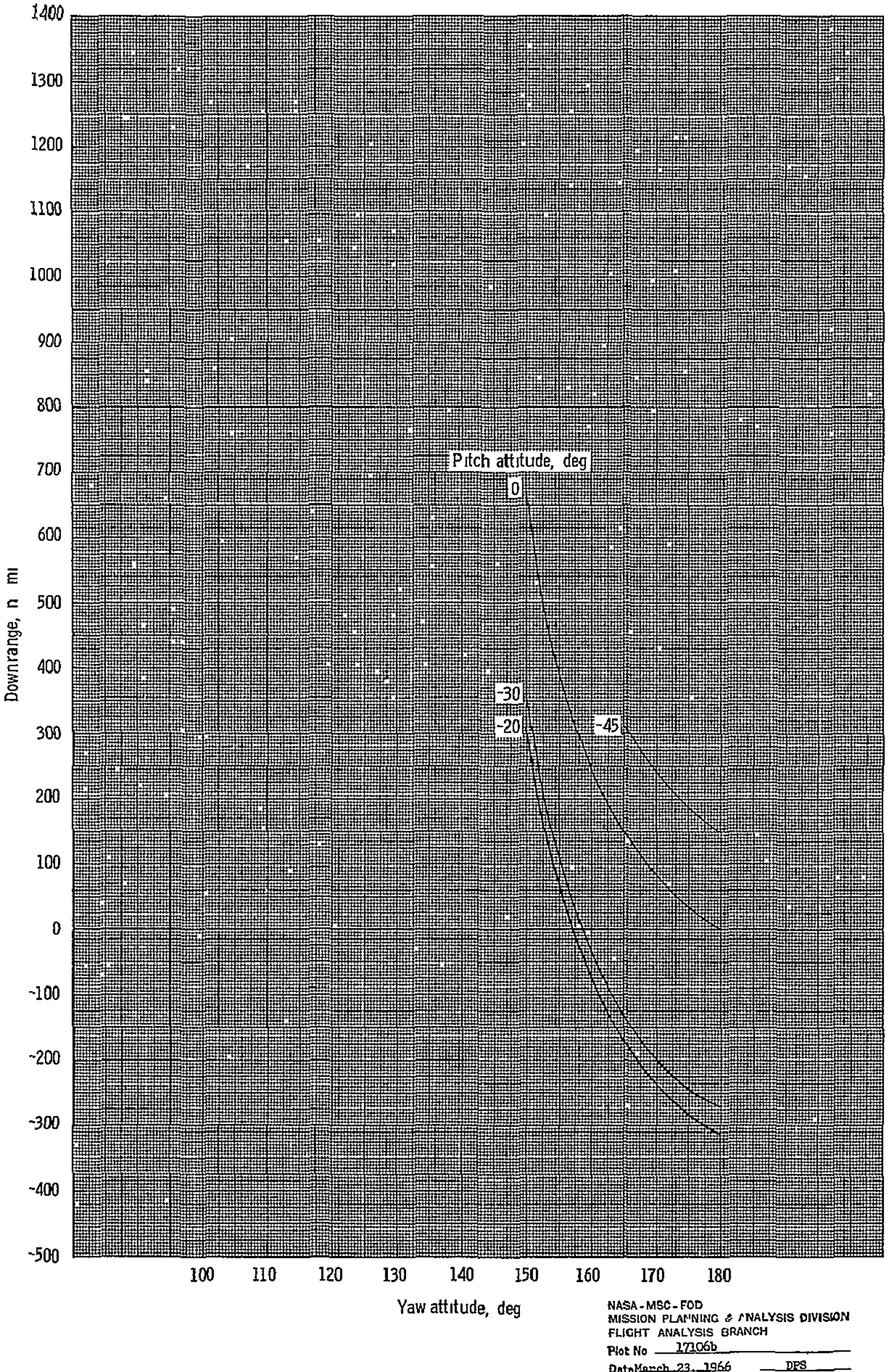
(e) ΔV = 2000 fps.

Figure 3 - Concluded.



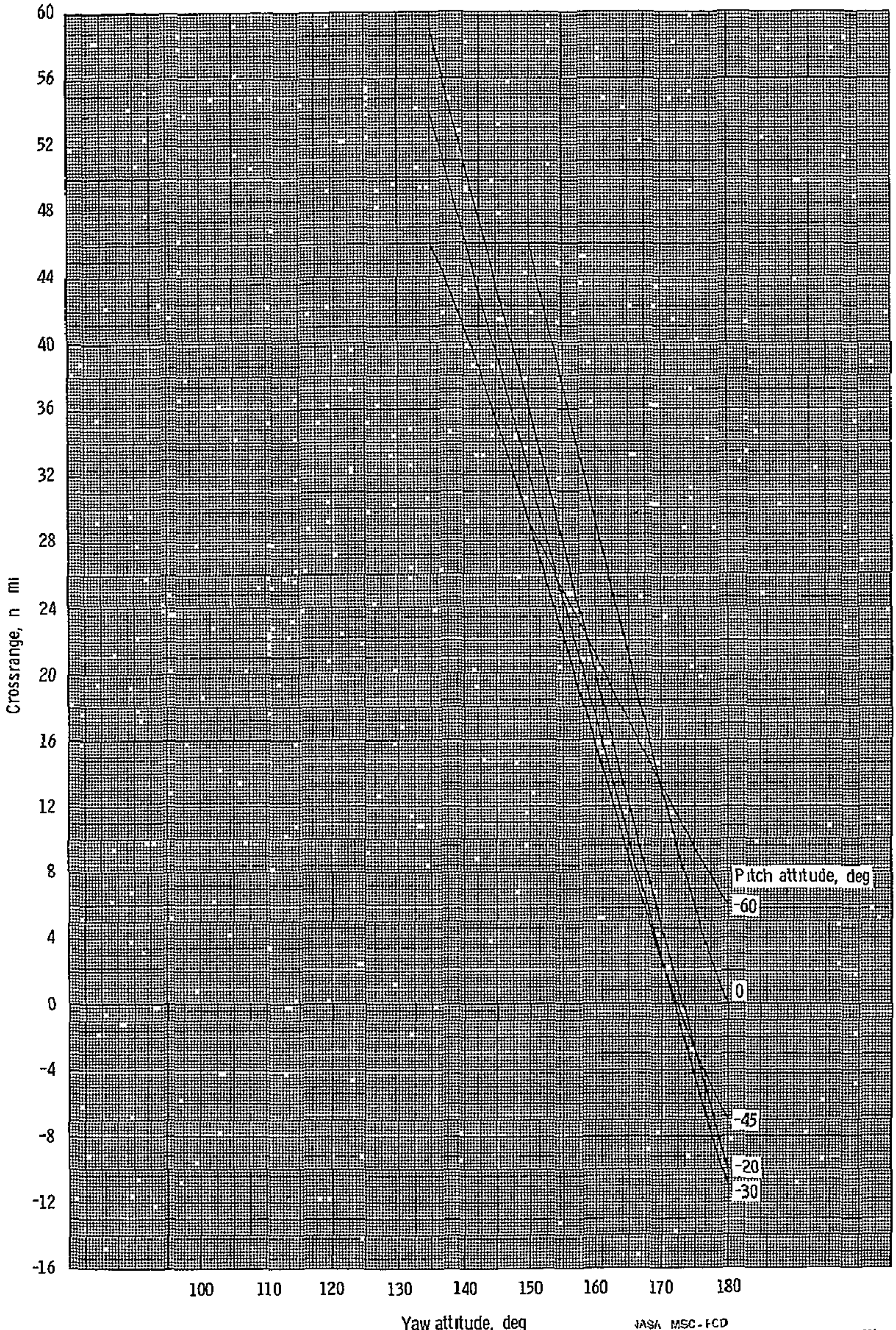
(a) ΔV = 500 fps.

Figure 4 - 200 nautical mile circular orbit for various burn attitudes with downrange or crossrange versus yaw attitudes for various pitches



(a) ΔV = 500 fps.

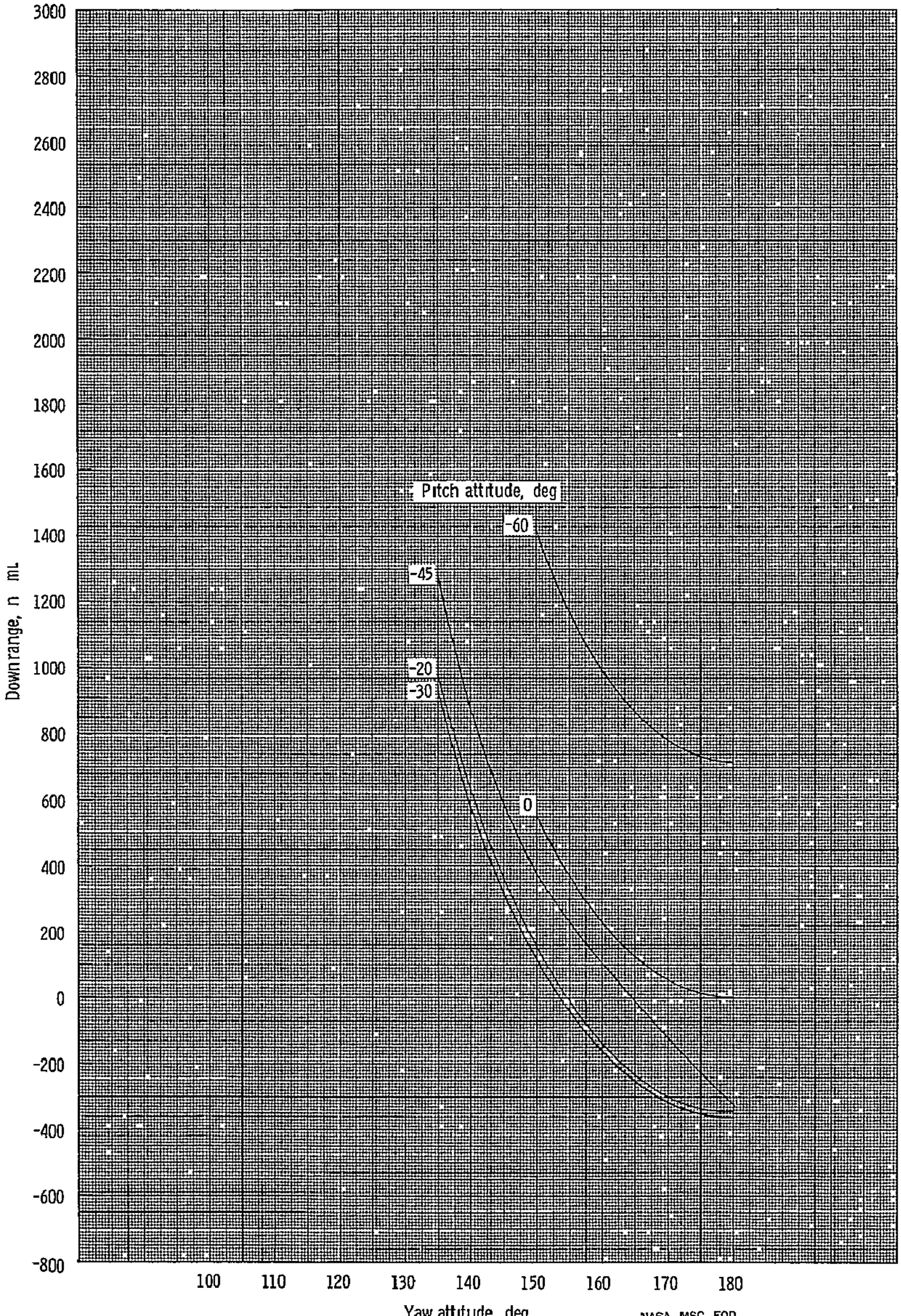
Figure 4. - Continued.



NASA MSC-FCD
MISSION P... DIVISION
FLIGHT ANALYSIS ...
Plot No 17106c
Date March 23, 1966 DPS

(b) $\Delta V \approx 600$ fps.

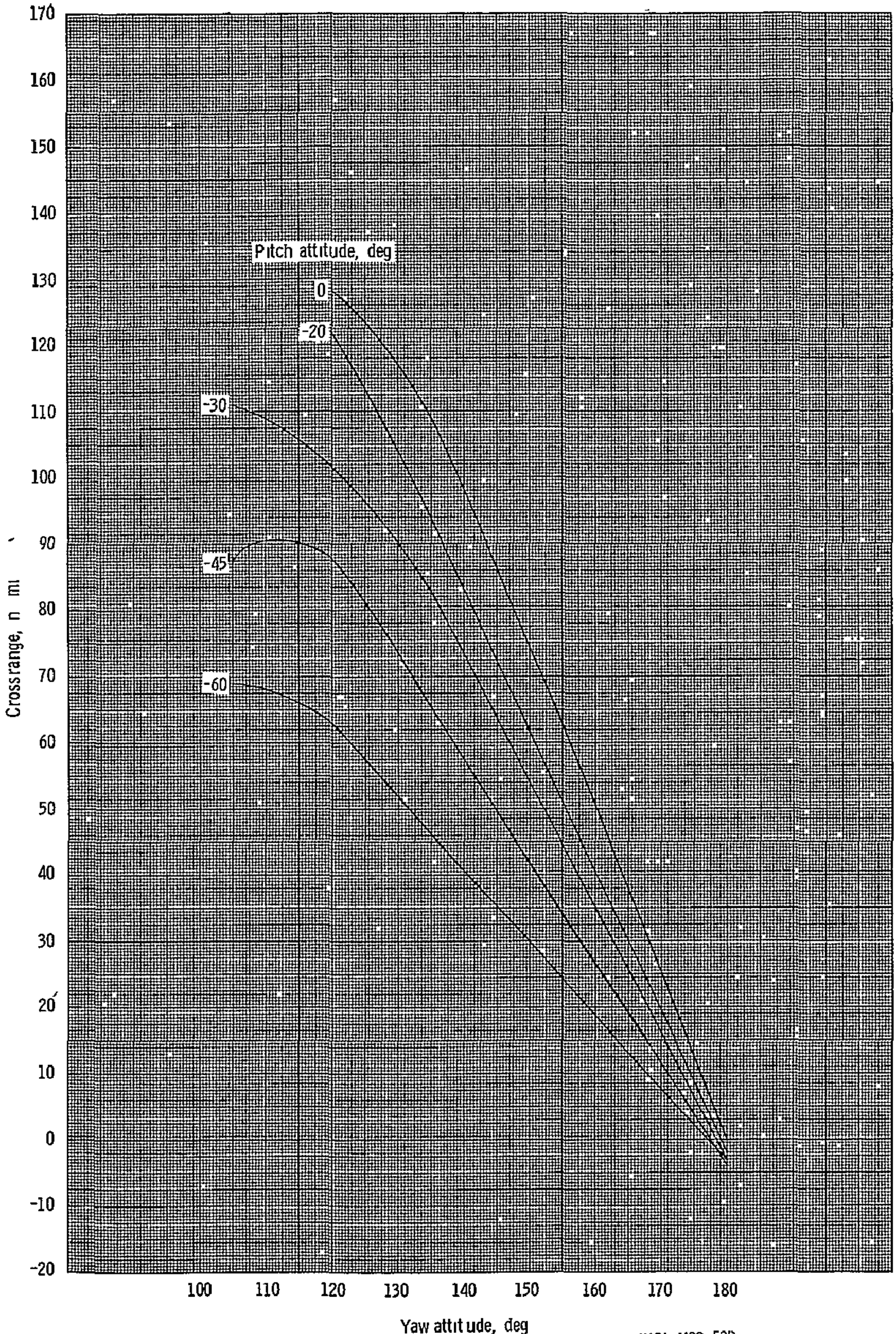
Figure 4. - Continued.



NASA MSC FOD
MISSION PLANNING & ANALYSIS DIVISION
FLIGHT ANALYSIS BRANCH
Plot No 17106d
Date March 23, 1966 DPS

(b) ΔV = 600 fps

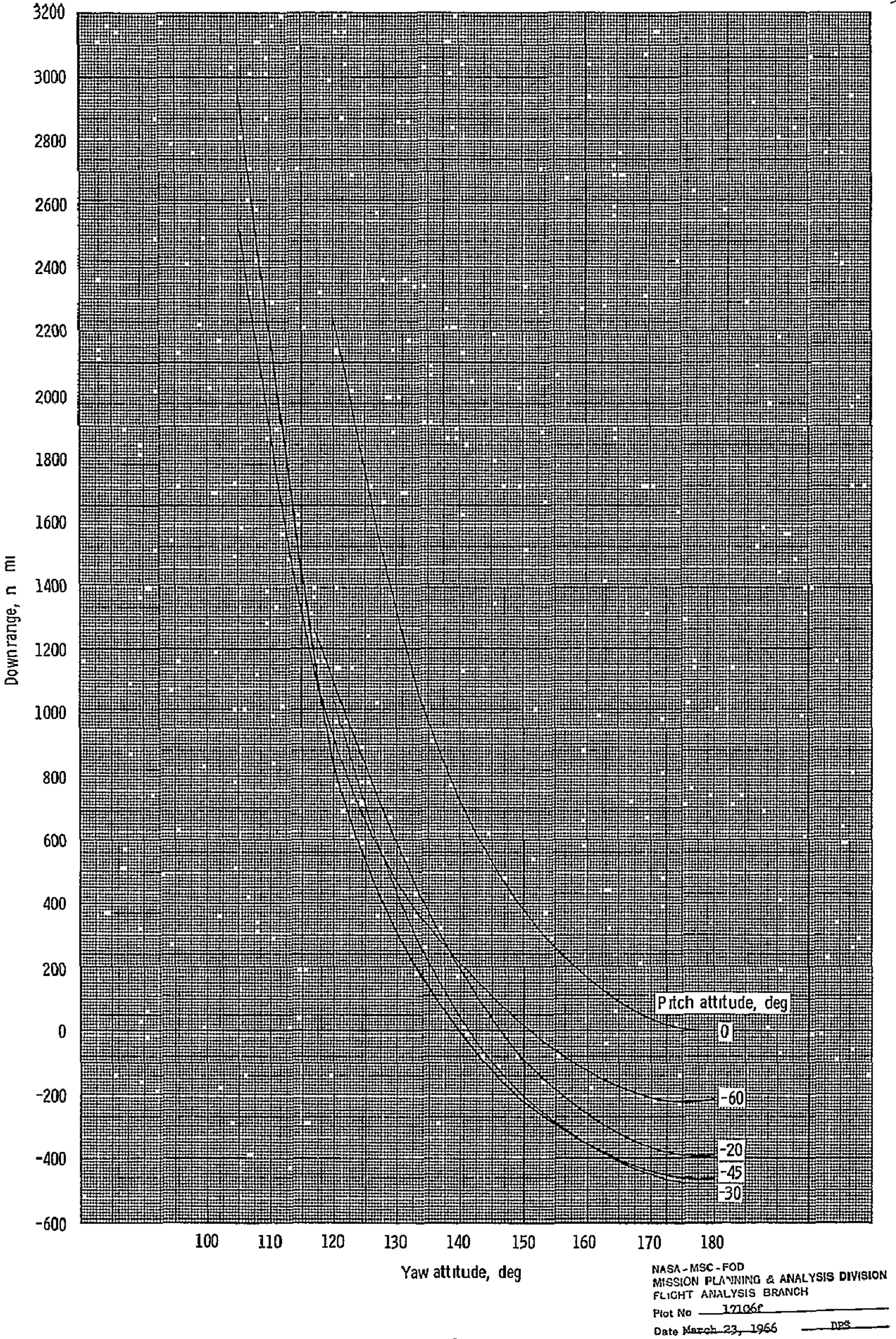
Figure 4. - Continued.



NASA MSC FOD
MISSION PLANNING & ANALYSIS DIVISION
FLIGHT ANALYSIS BRANCH
Plot No 17106e
Date March 23, 1966 DPS

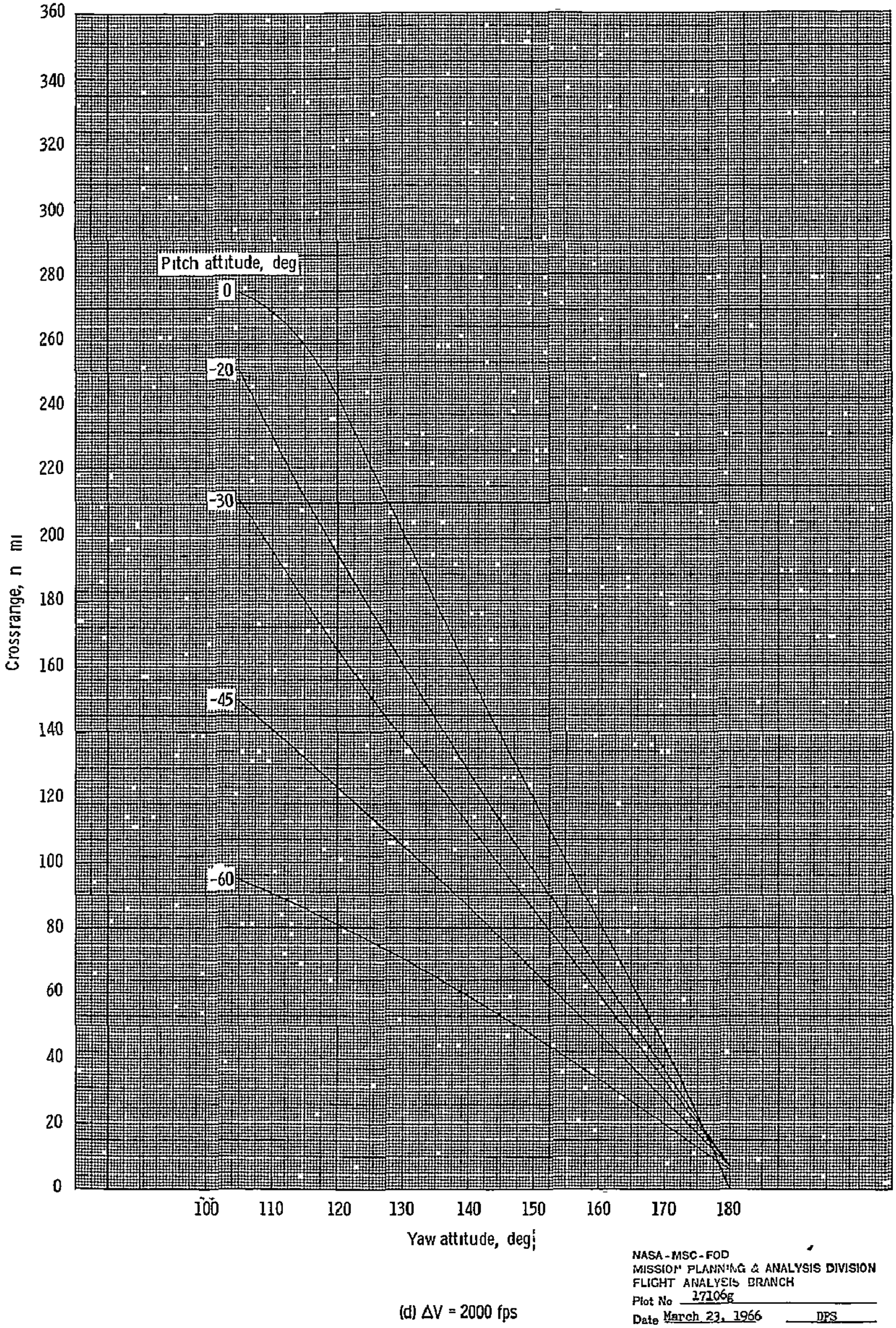
(c) ΔV = 1000 fps.

Figure 4 - Continued



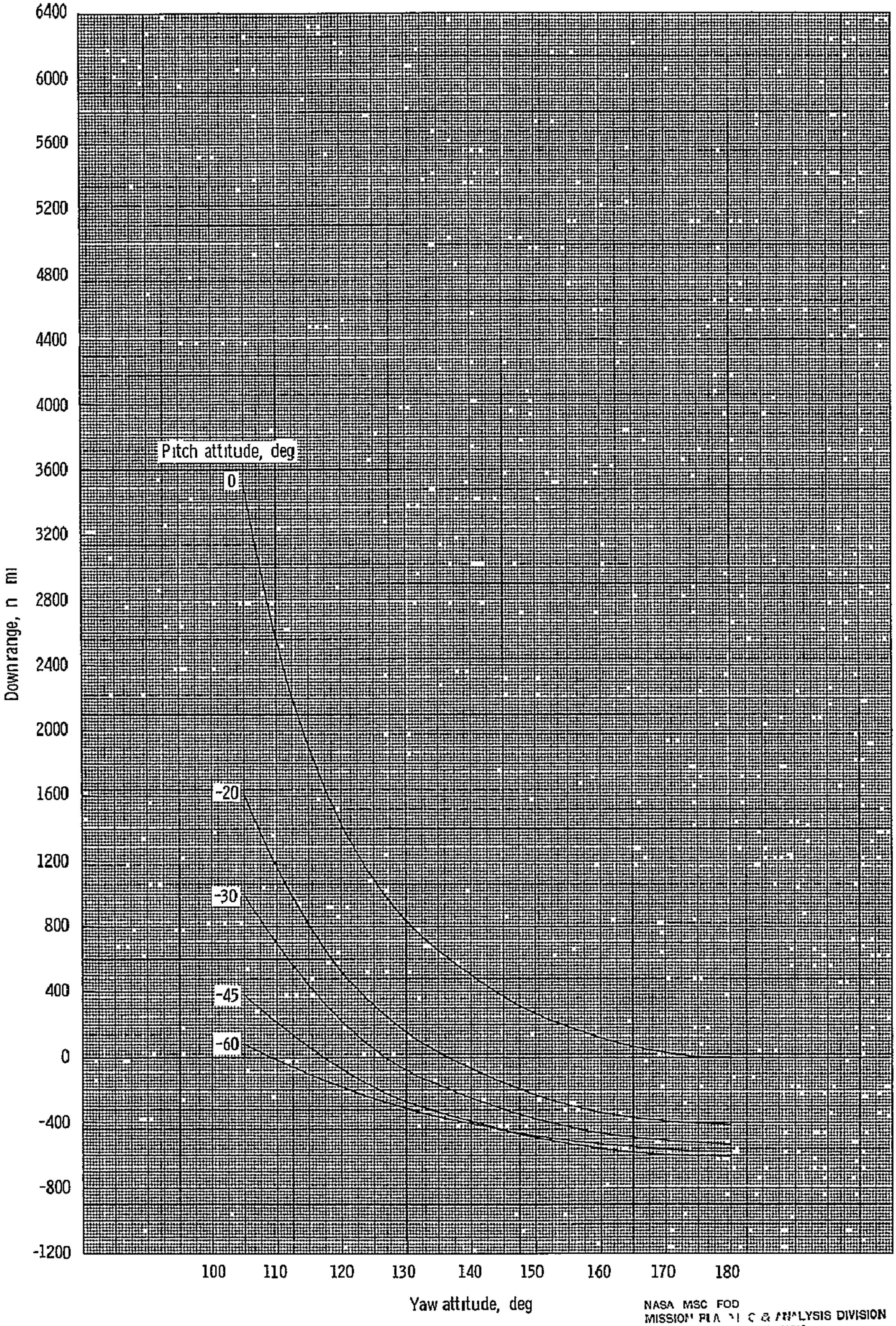
(c) ΔV = 1000 fps

Figure 4. - Continued



(d) ΔV = 2000 fps

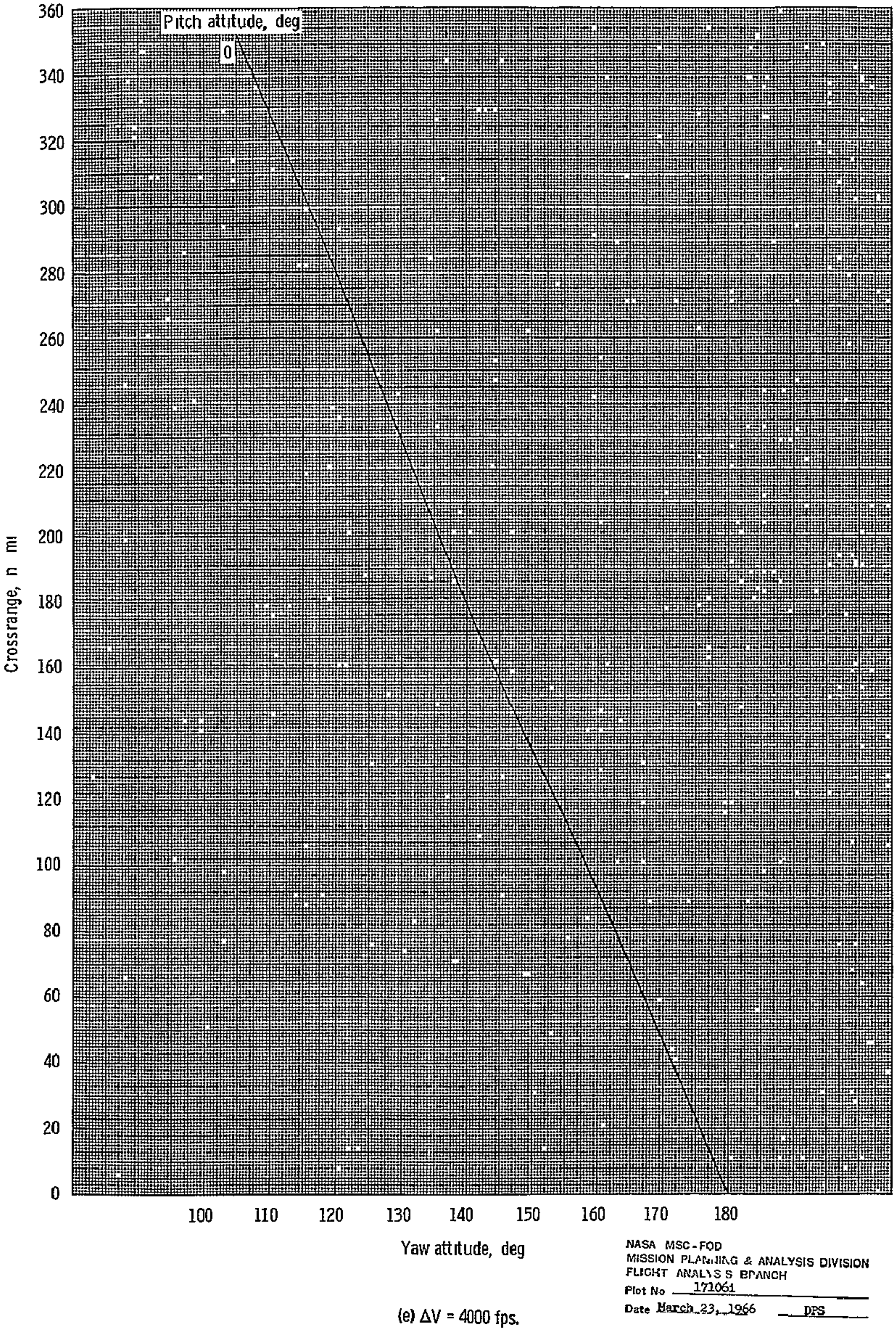
Figure 4 - Continued.



NASA MSC FOD
MISSION PL[illegible] ANALYSIS DIVISION
FLIGHT [illegible]
Plot No 17106h
Date March 23, 1966 DPS

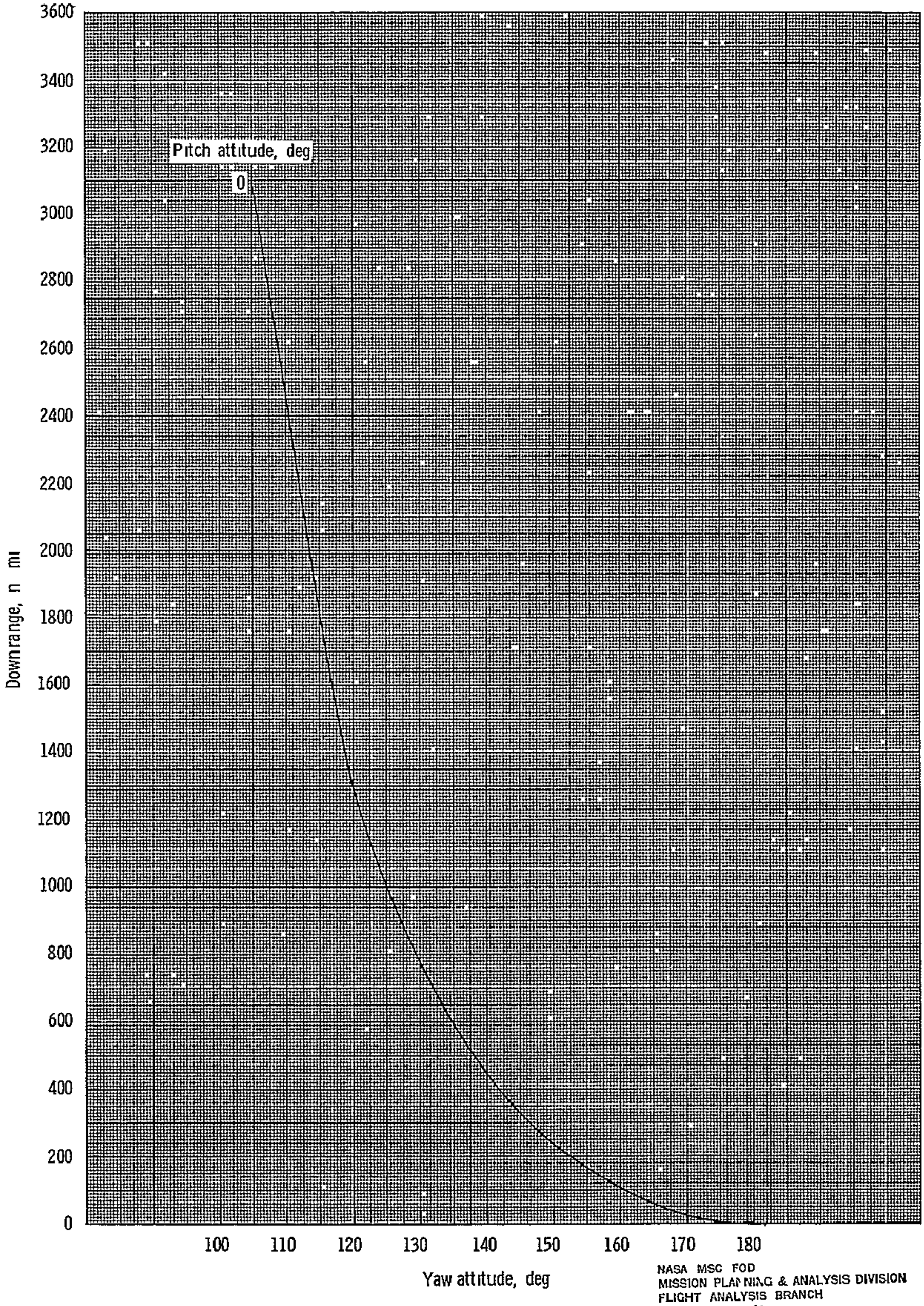
(d) ΔV = 2000 fps.

Figure 4. - Continued



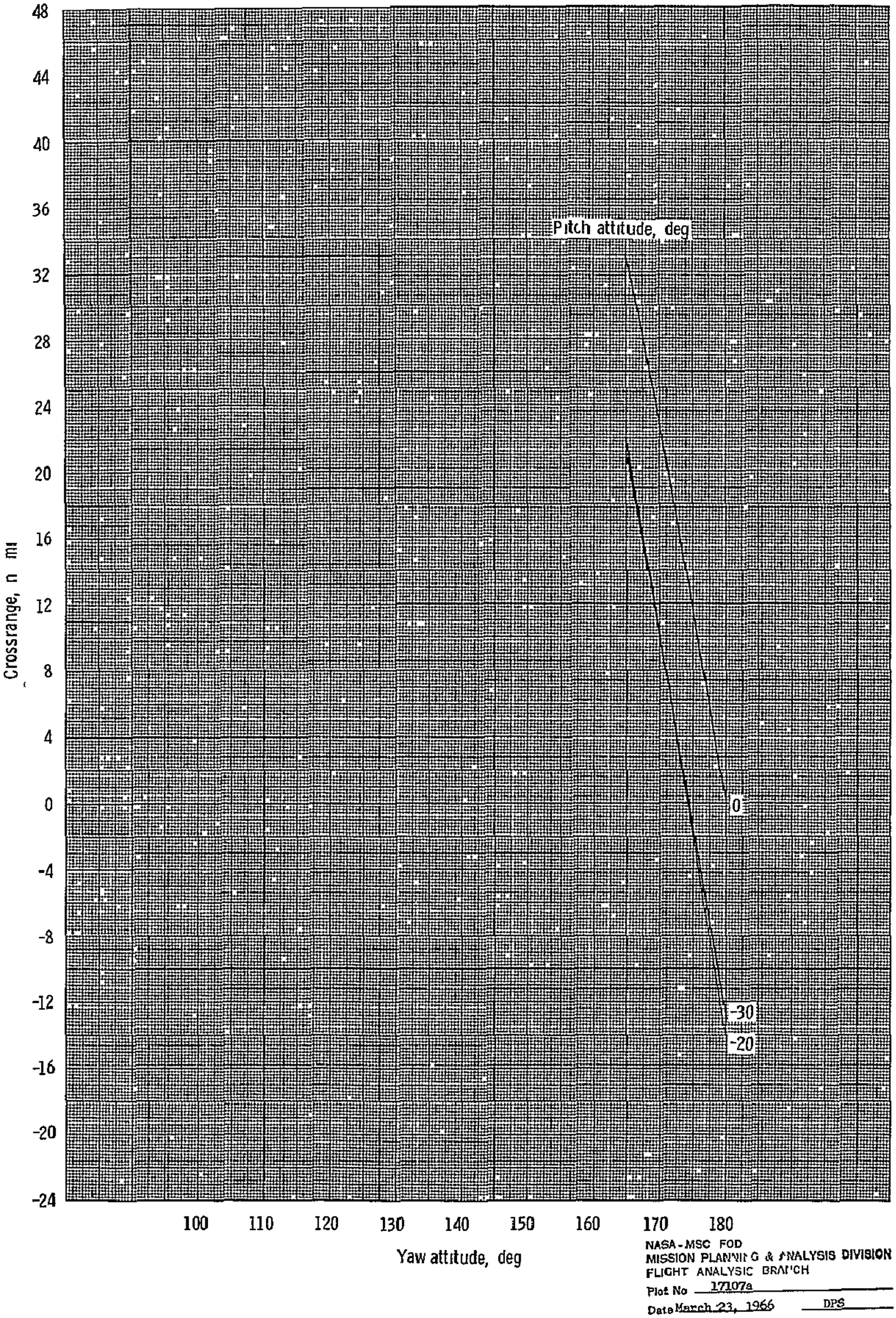
(e) ΔV = 4000 fps.

Figure 4. - Continued.



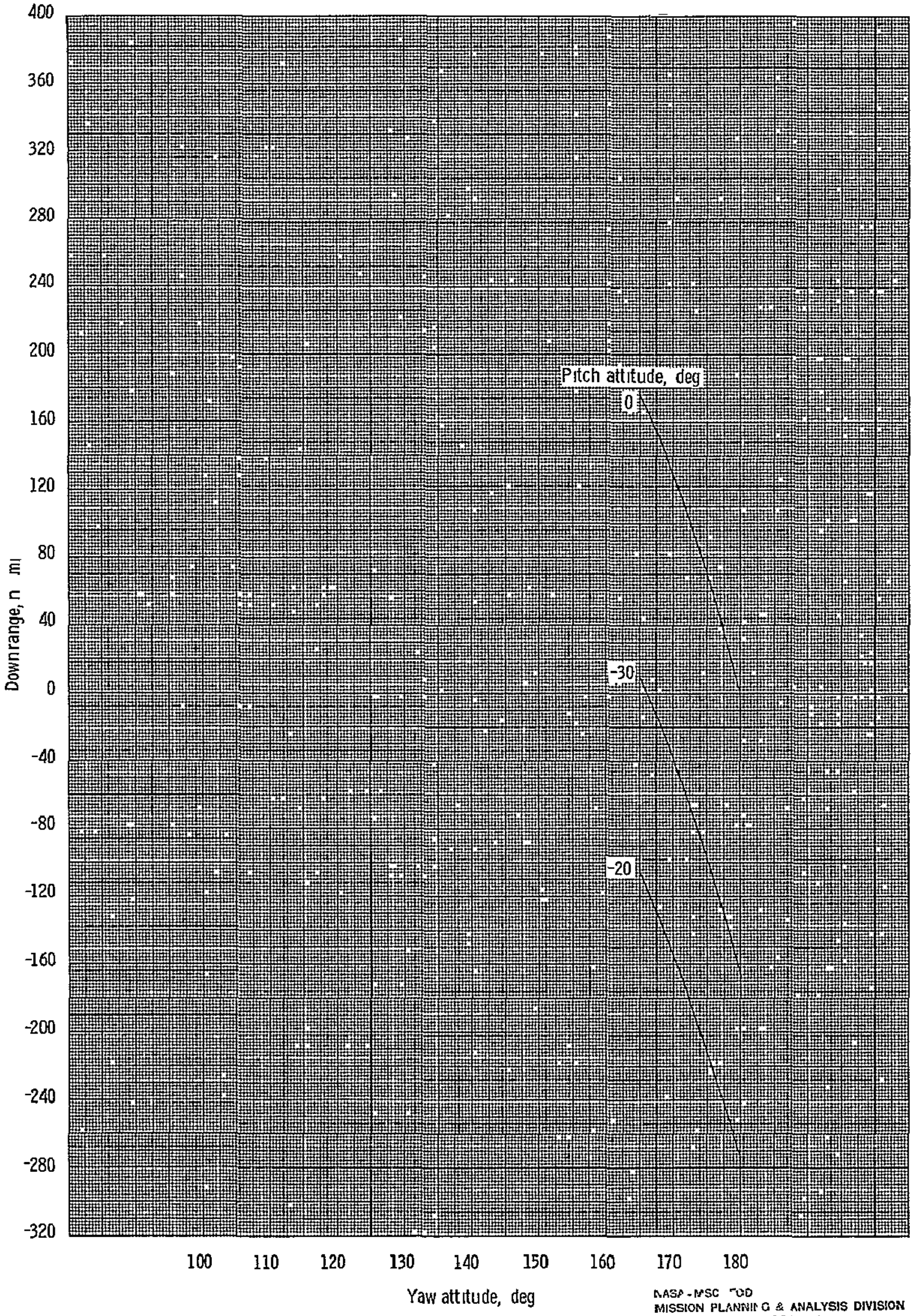
(e) ΔV = 4000 fps.

Figure 4. - Concluded.



(a) ΔV = 1000 fps.

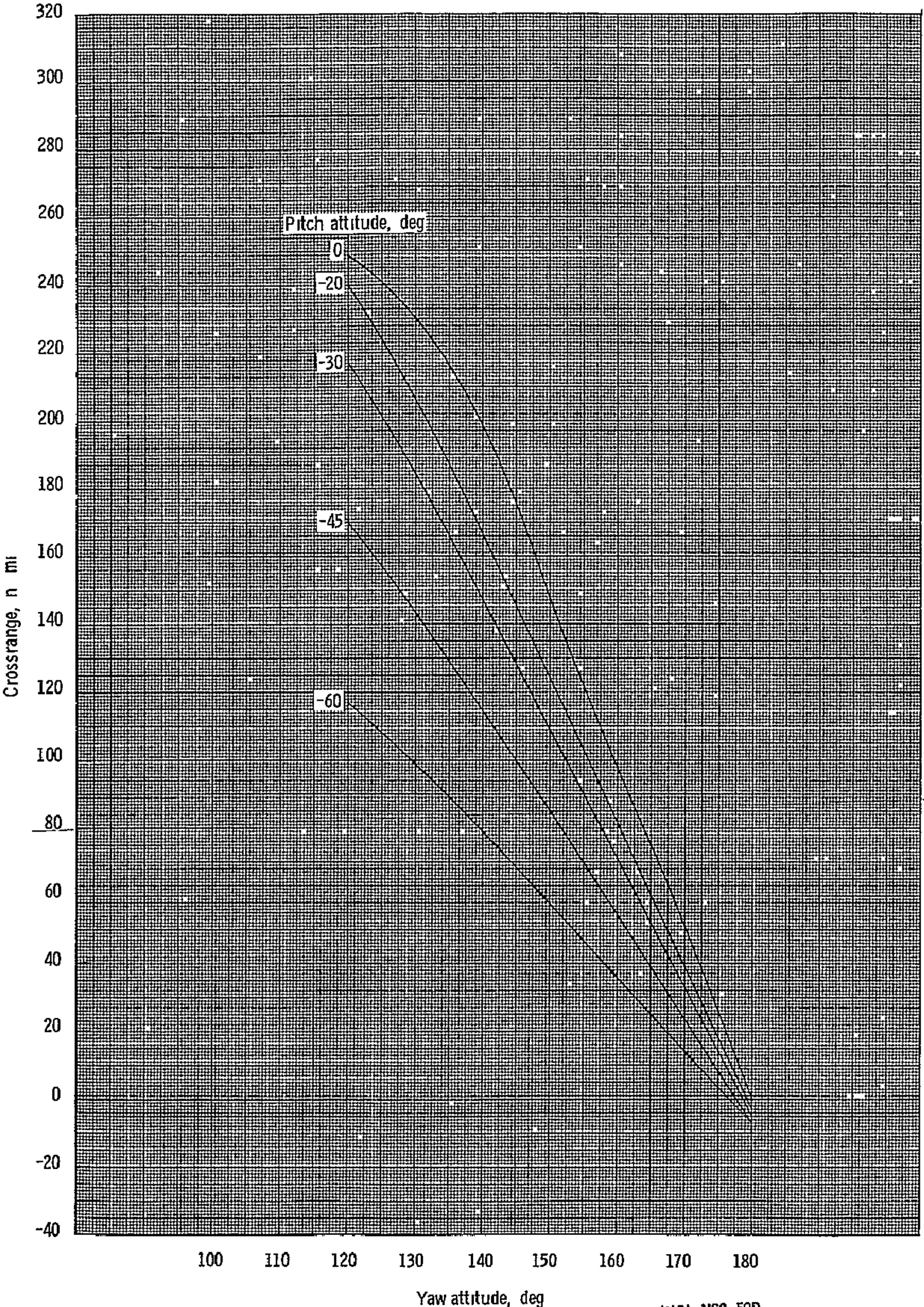
Figure 5 - 400 nautical mile circular orbit for various burn attitudes with downrange or crossrange versus yaw attitudes for various pitches



NASA-MSC FOD
MISSION PLANNING & ANALYSIS DIVISION
FLIGHT ANALYSIS BRANCH
Plot No 17107b
Date March 23, 1966 DPS

(a) ΔV = 1000 fps

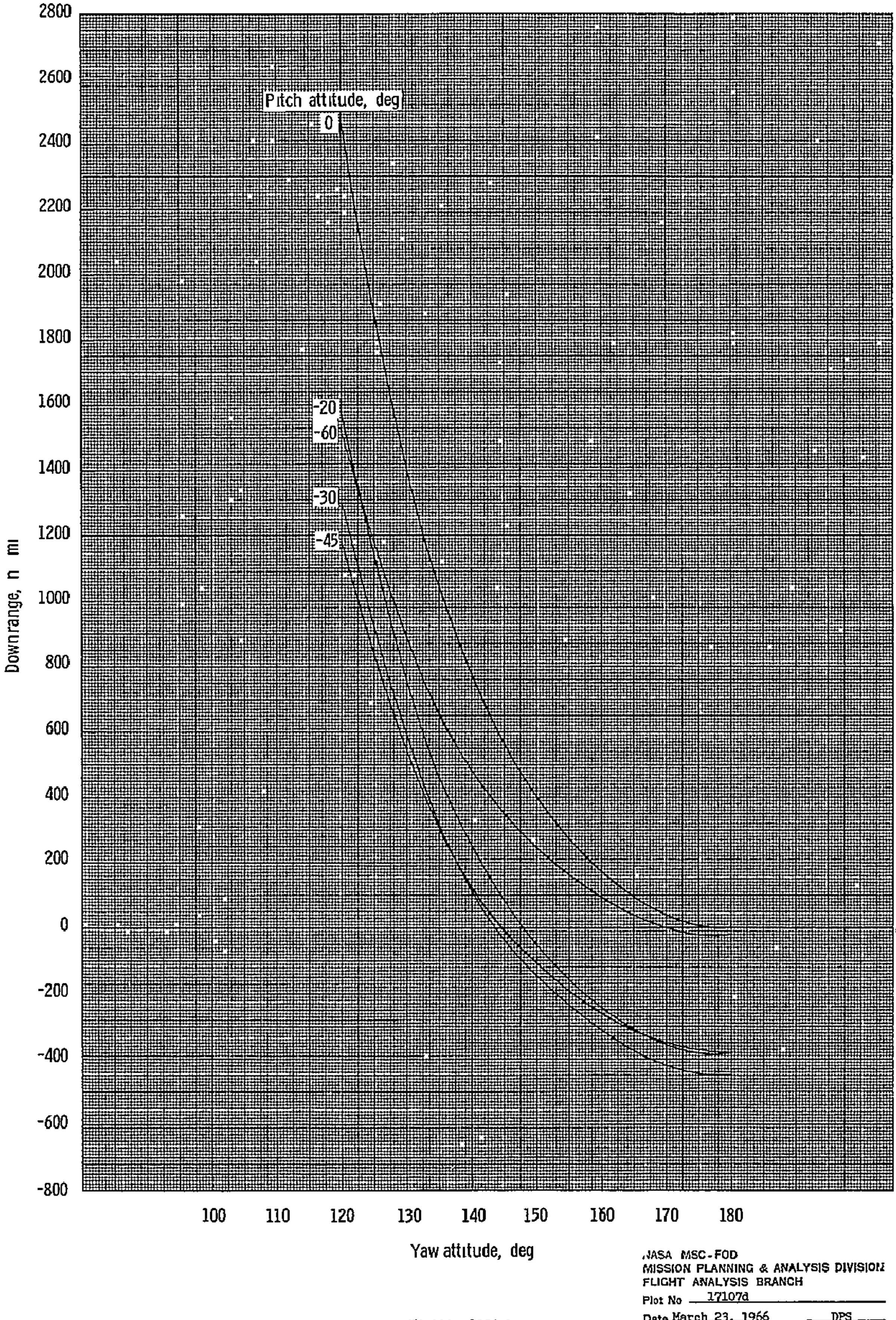
Figure 5 - Continued.



NASA-MSC-FOD
MISSION PLANNING & ANALYSIS DIVISION
FLIGHT ANALYSIS BRANCH
Plot No 17107c
Date March 23, 1966 DPS

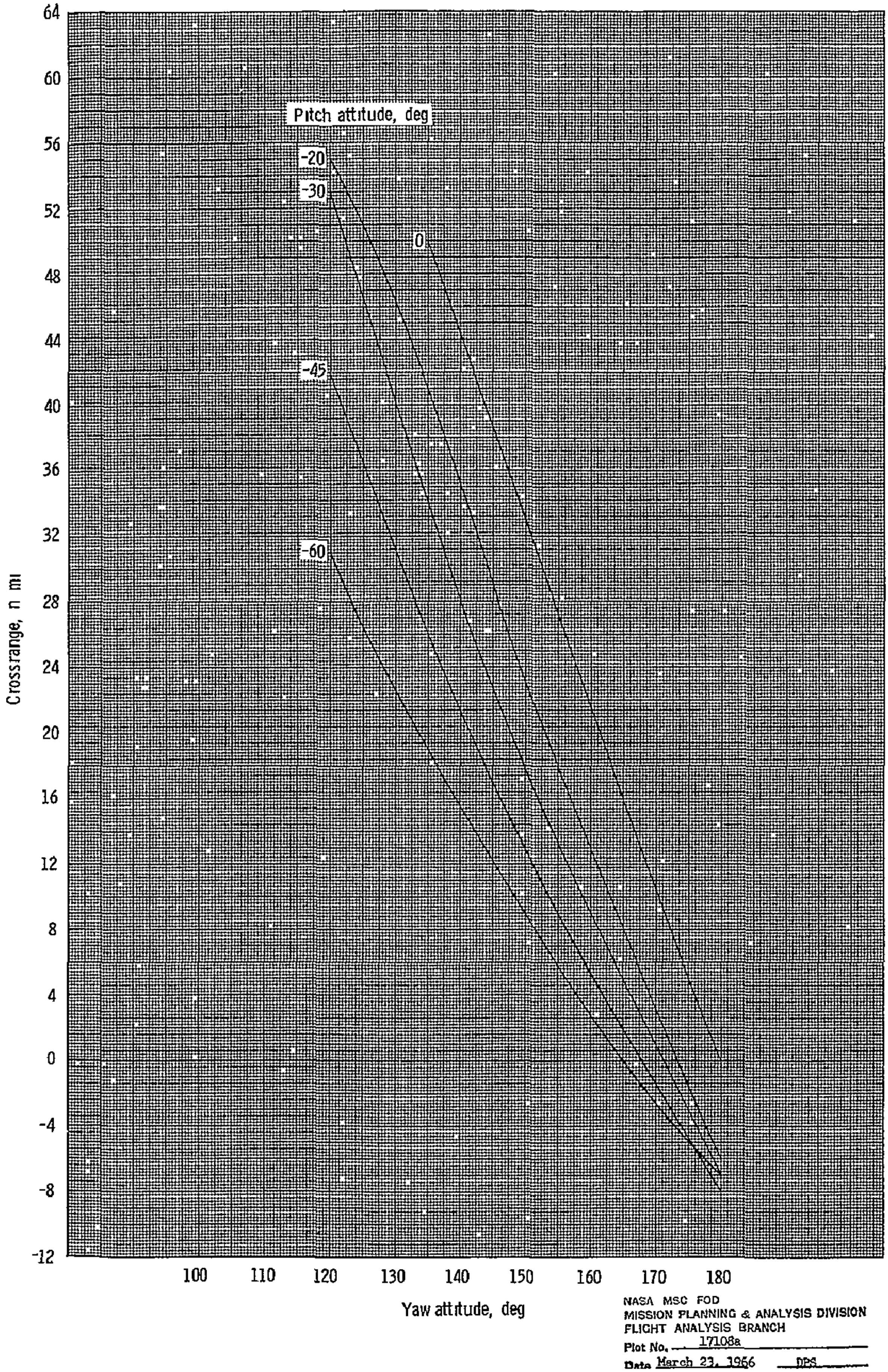
(b) ΔV = 2000 fps.

Figure 5 - Continued.



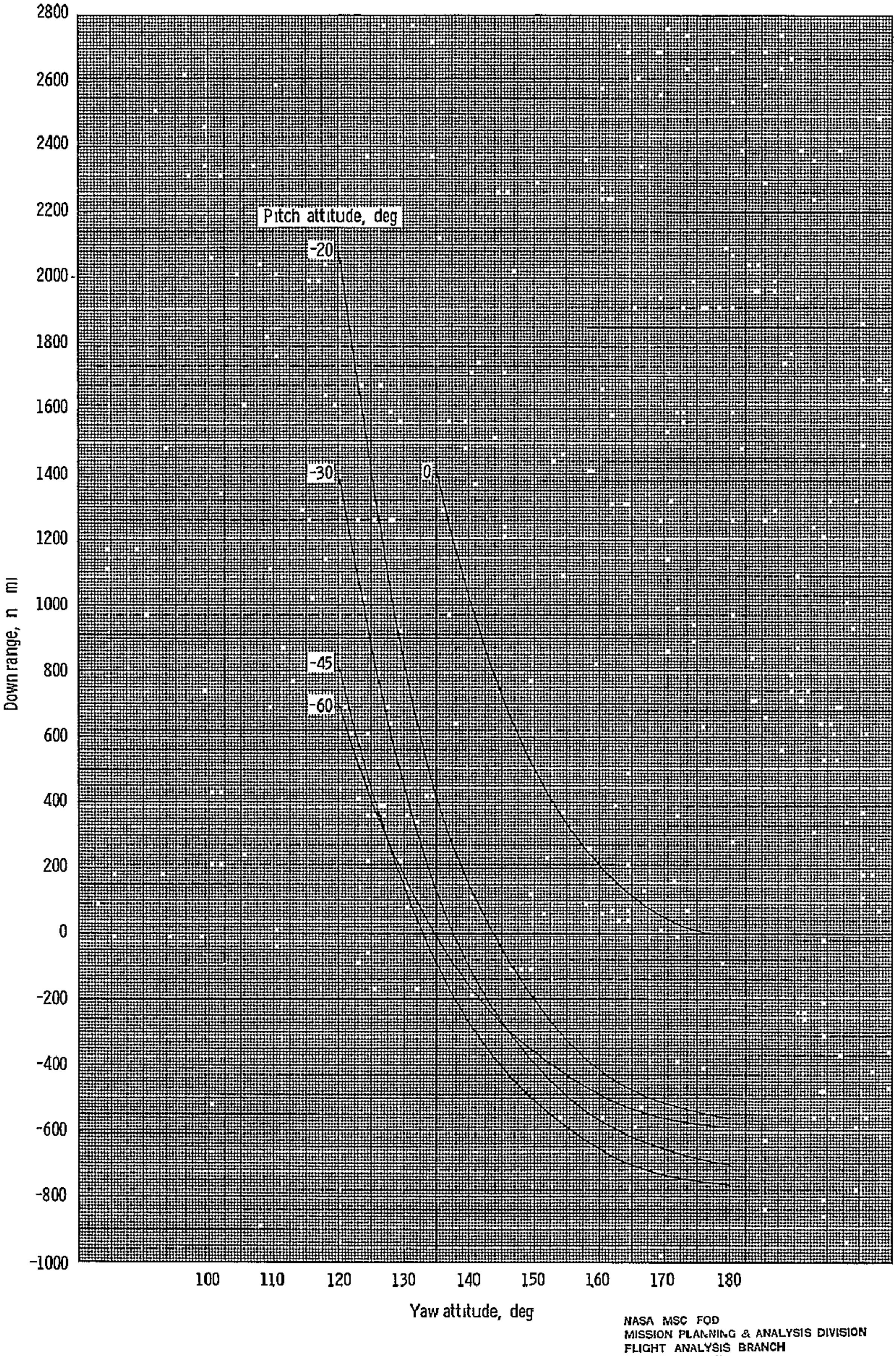
(b) ΔV = 2000 fps.

Figure 5 - Concluded.



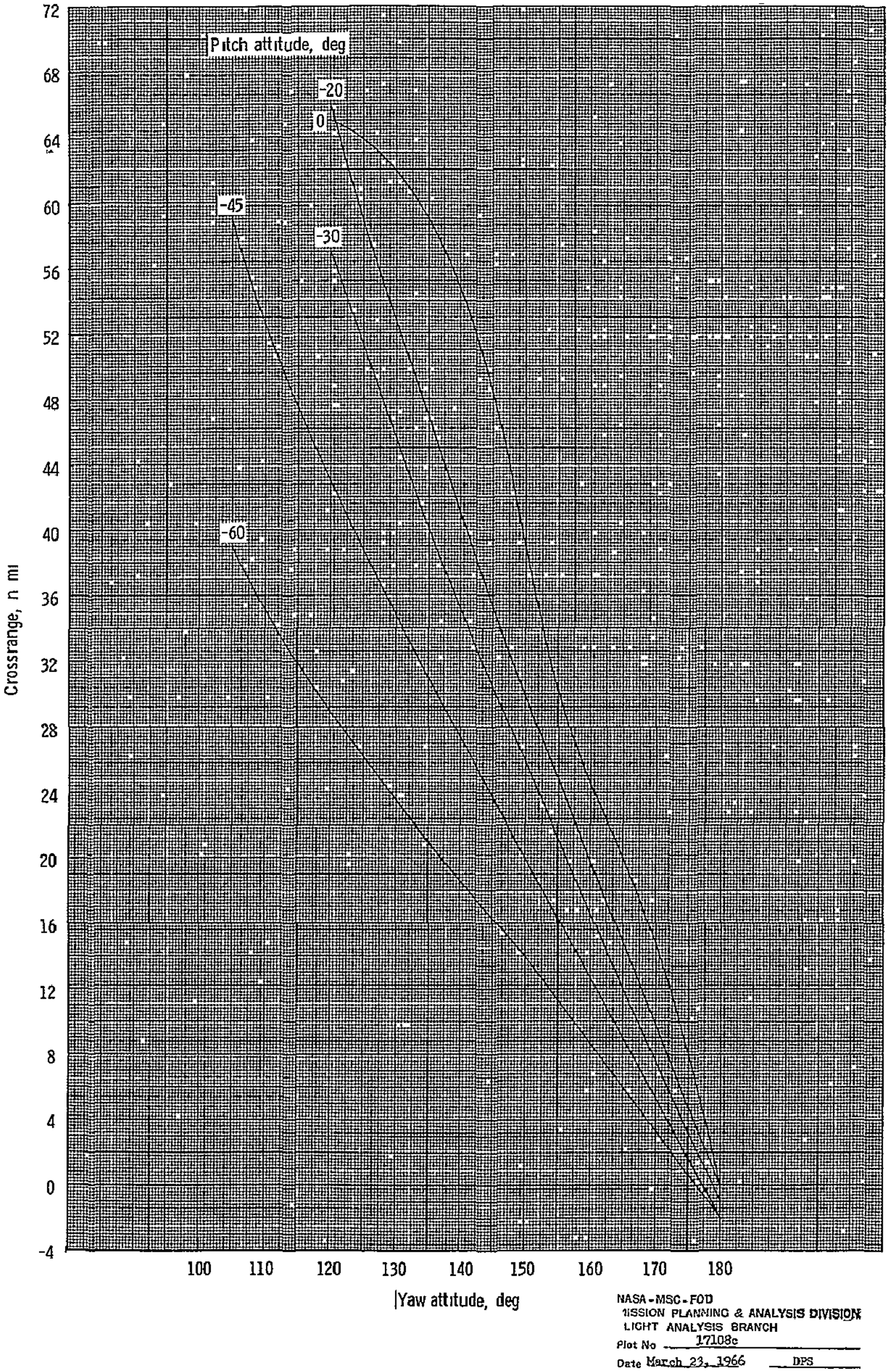
(a) ΔV = 400 fps

Figure 6 - 85/150 elliptical orbit with burn at perigee for various burn attitudes with downrange or crossrange versus yaw attitude for various pitches



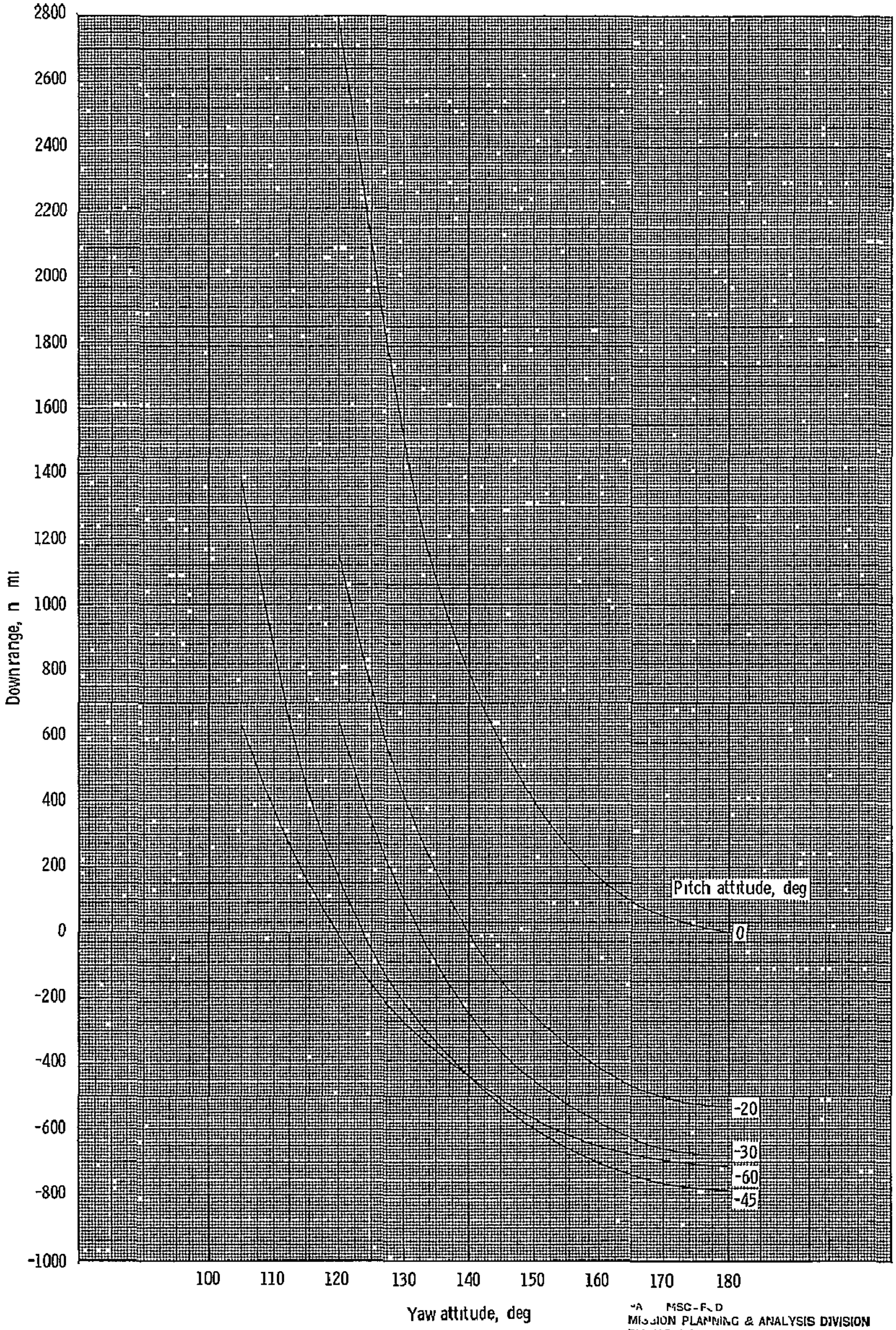
(a) ΔV = 400 fps

Figure 6. - Continued



(b) ΔV = 500 fps.

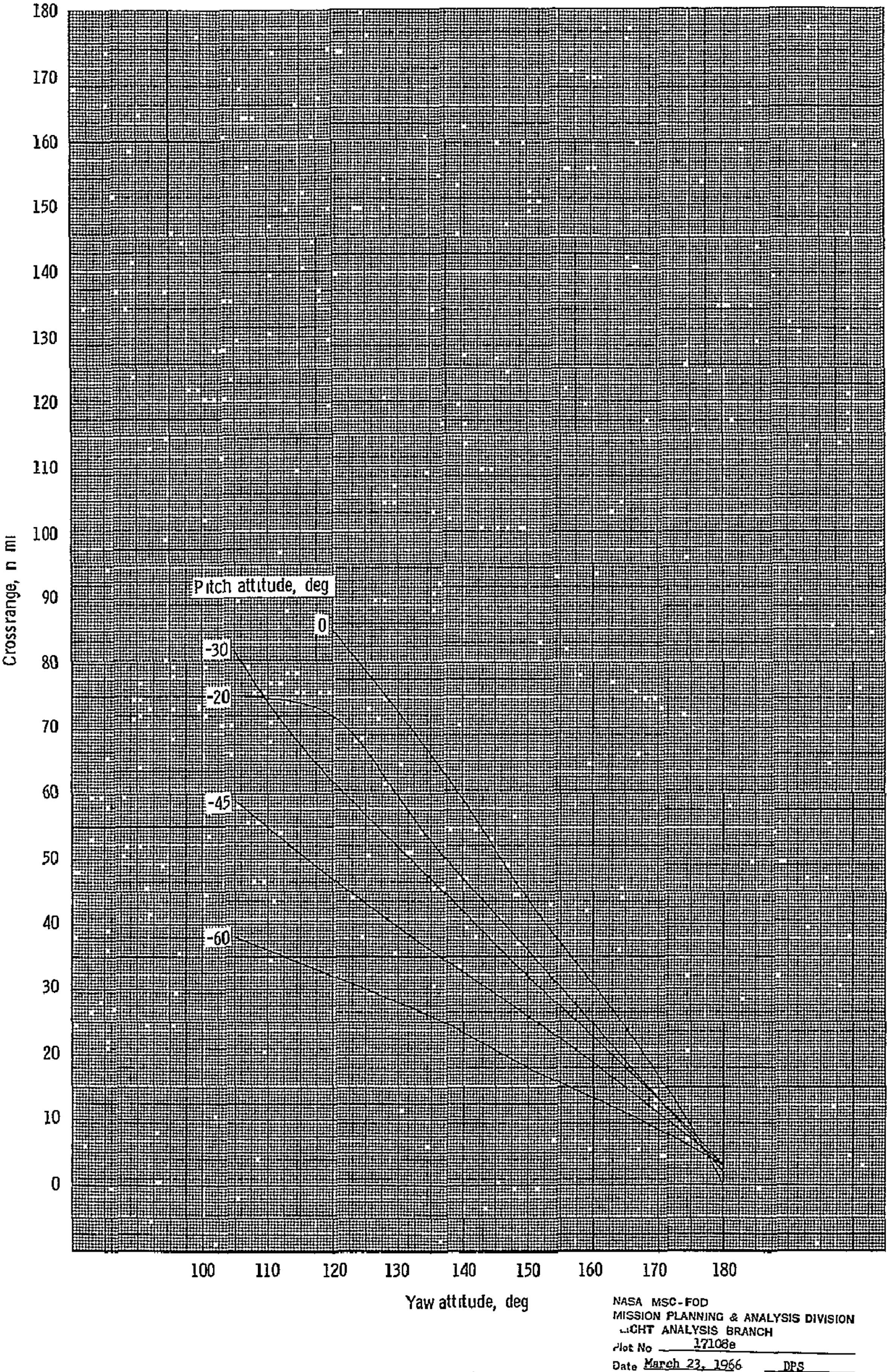
Figure 6 - Continued.



MSC-FOD
MISSION PLANNING & ANALYSIS DIVISION
FLIGHT ANALYSIS BRANCH
Plot No 17108d
Date March 23, 1966 DPS

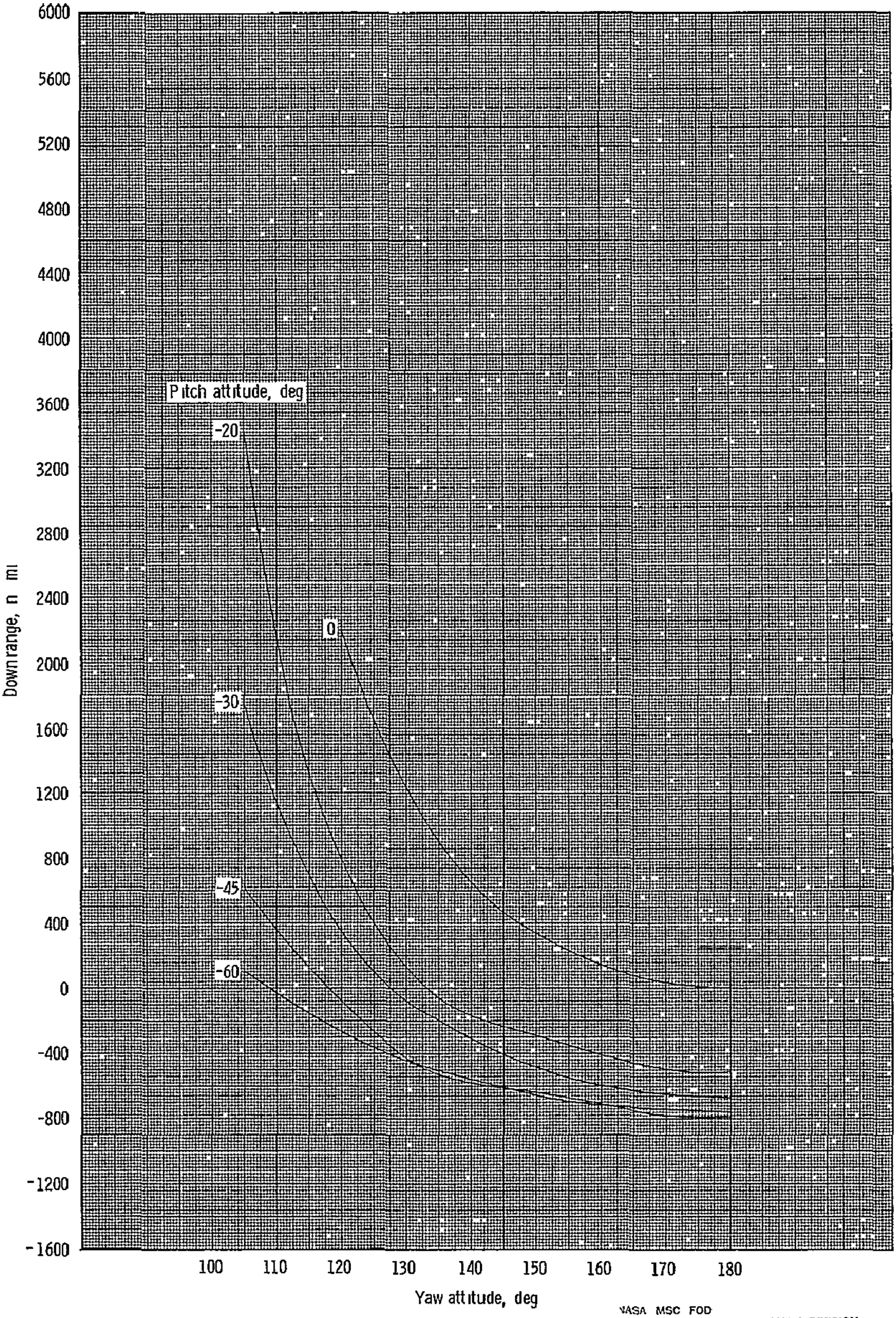
(b) ΔV = 500 fps.

Figure 6 - Continued.



(c) ΔV = 600 fps

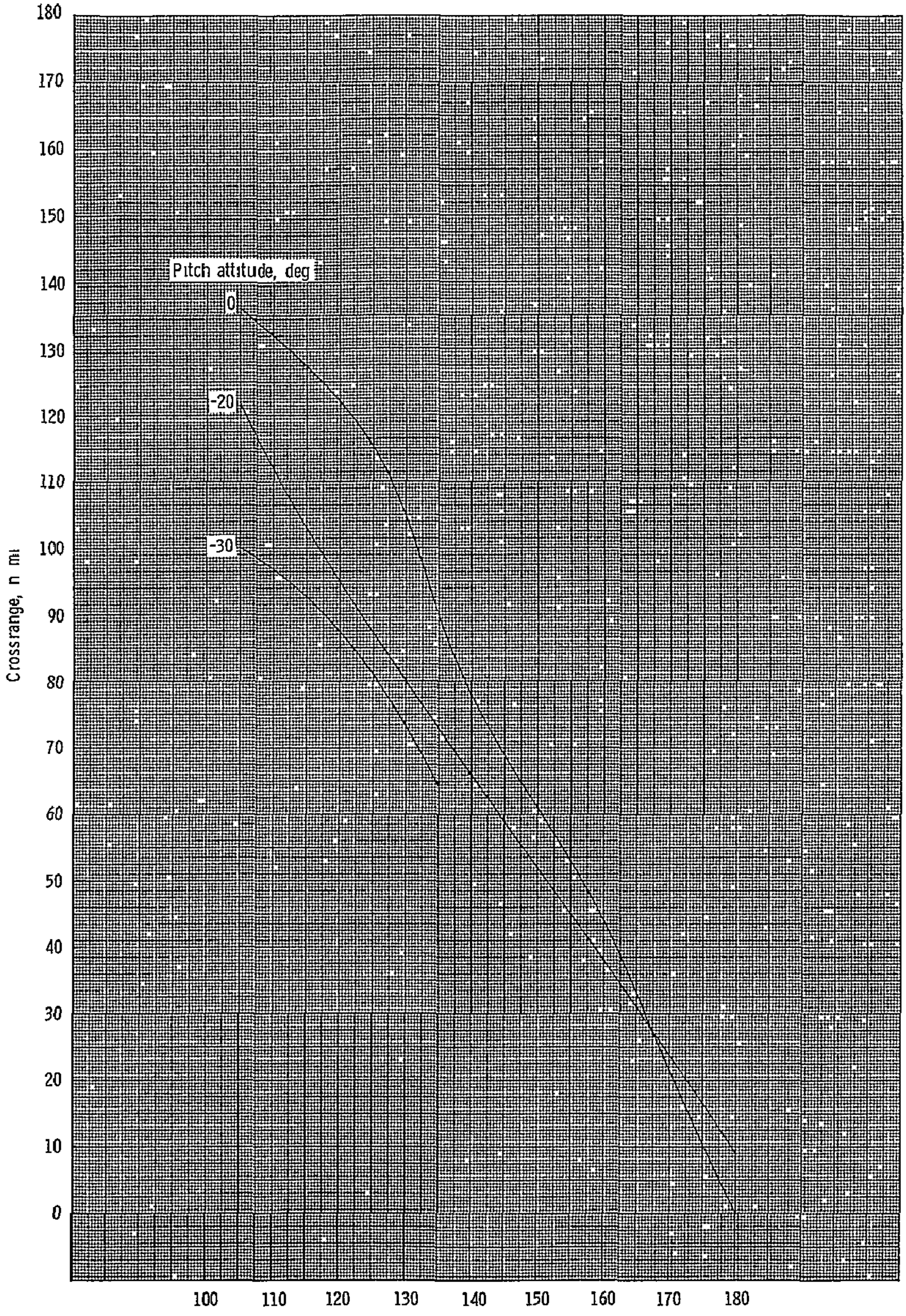
Figure 6 - Continued



NASA MSC FOD
MISSION PLANNING & ANALYSIS DIVISION
FLIGHT ANALYSIS BRANCH
Plot No 17108f
Date March 23, 1966

(c) ΔV = 600 fps

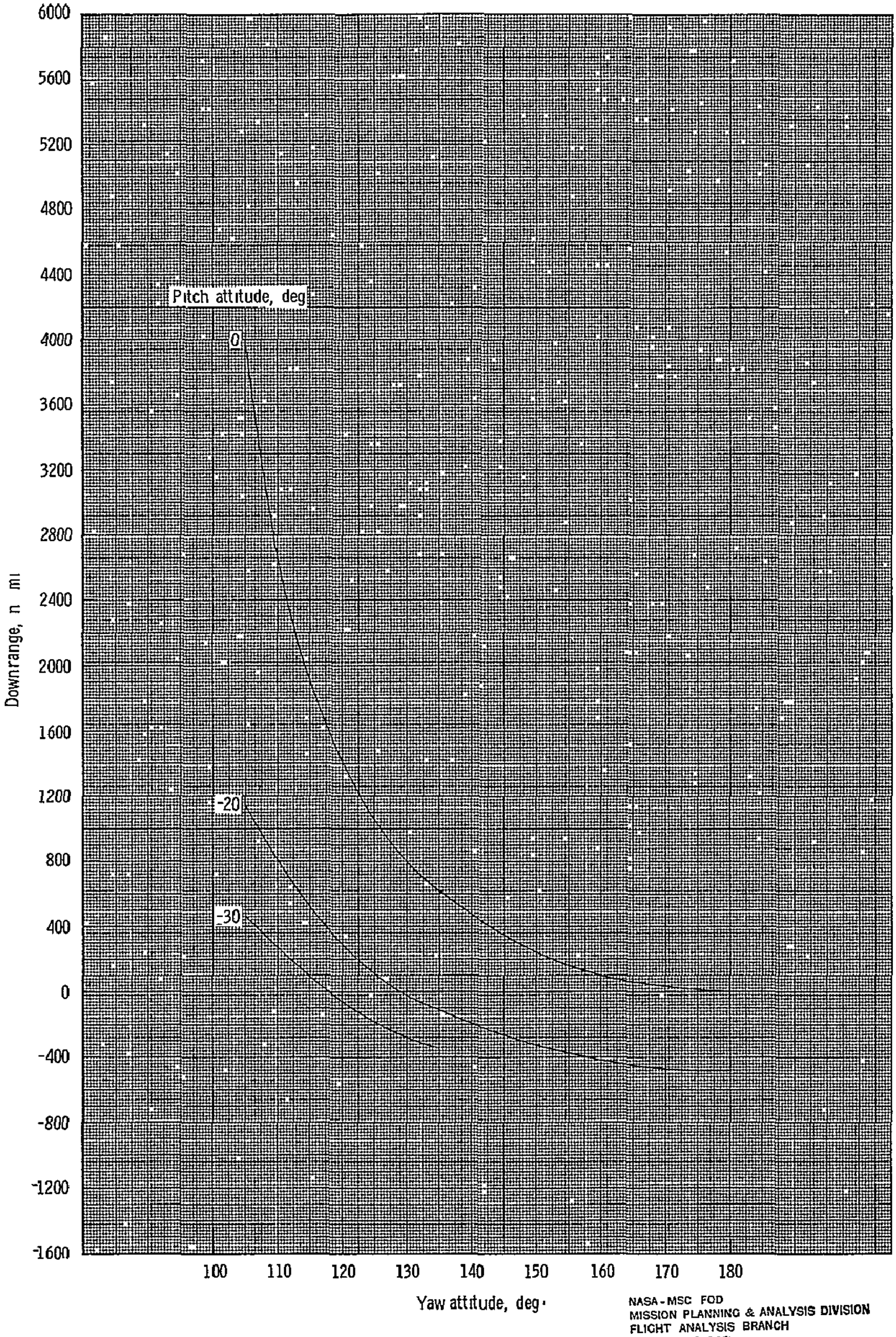
Figure 6 - Continued



NASA MSC FOD
MISSION PLANNING & ANALYSIS DIVISION
FLIGHT ANALYSIS BRANCH
Plot No 17108g
Date March 23, 1966 DPS

(d) ΔV = 1000 fps

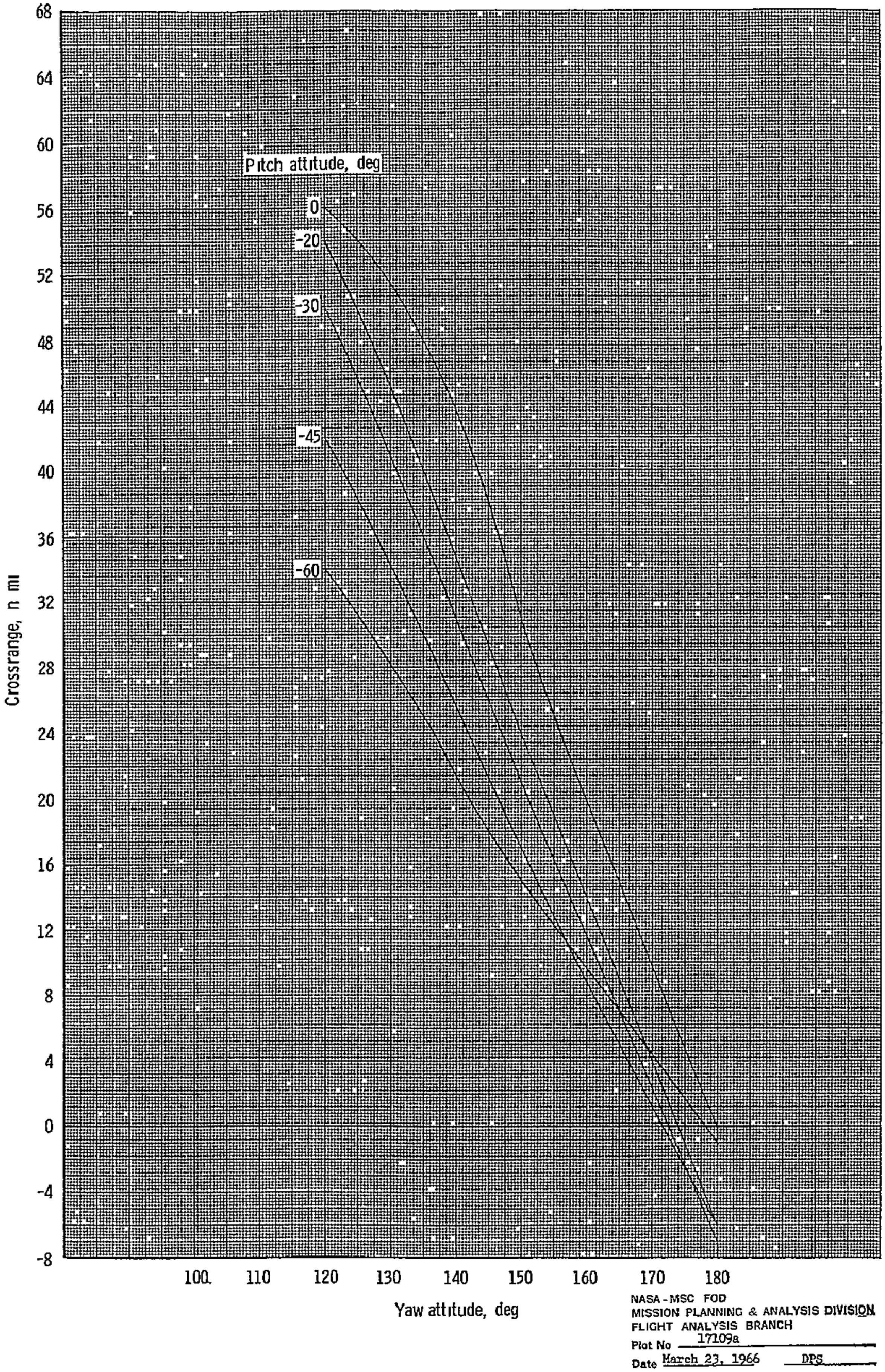
Figure 6 - Continued.



NASA-MSC FOD
MISSION PLANNING & ANALYSIS DIVISION
FLIGHT ANALYSIS BRANCH
Plot No 17108h
Date March 23, 1966 DPS

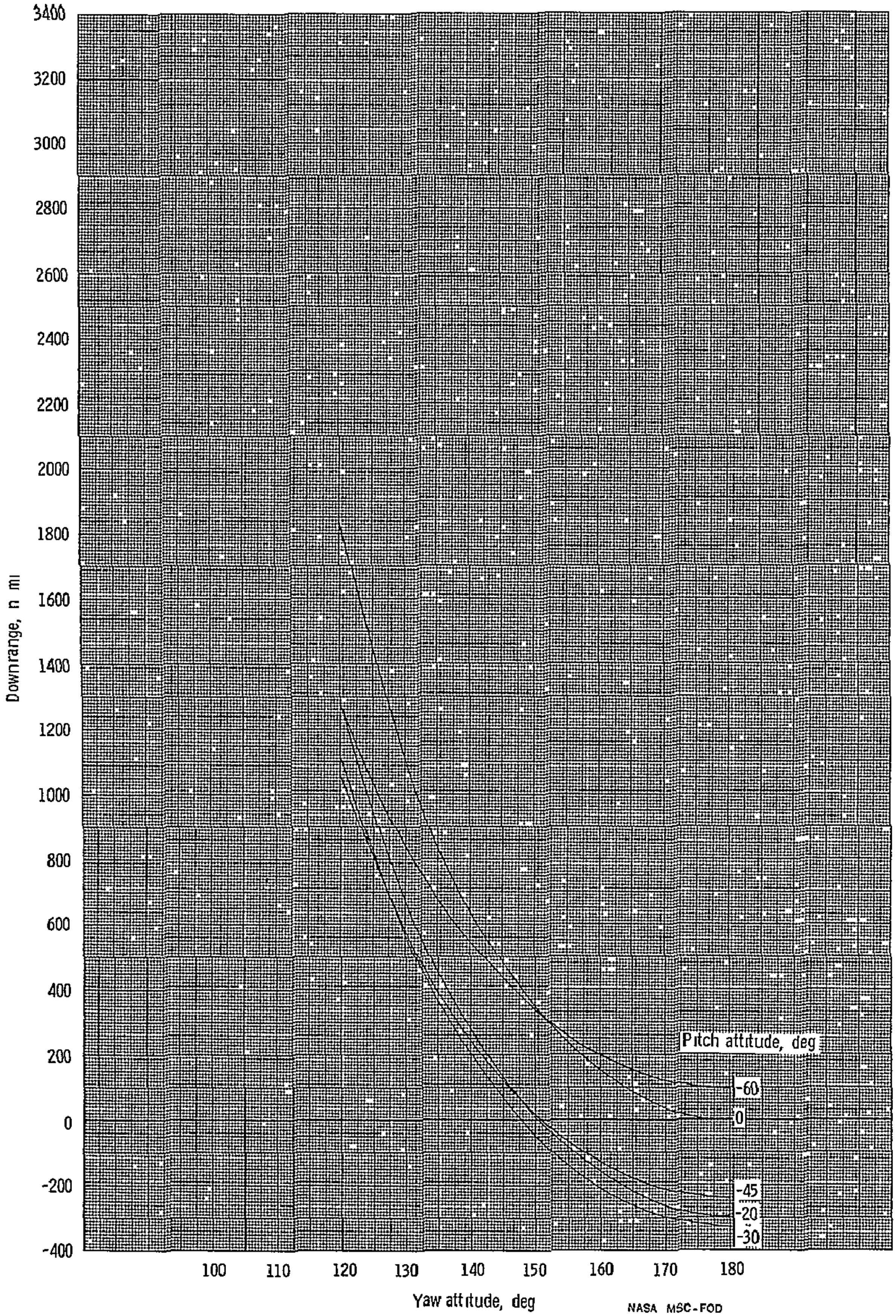
(d) ΔV = 1000 fps

Figure 6. - Concluded.



(a) ΔV = 400 fps.

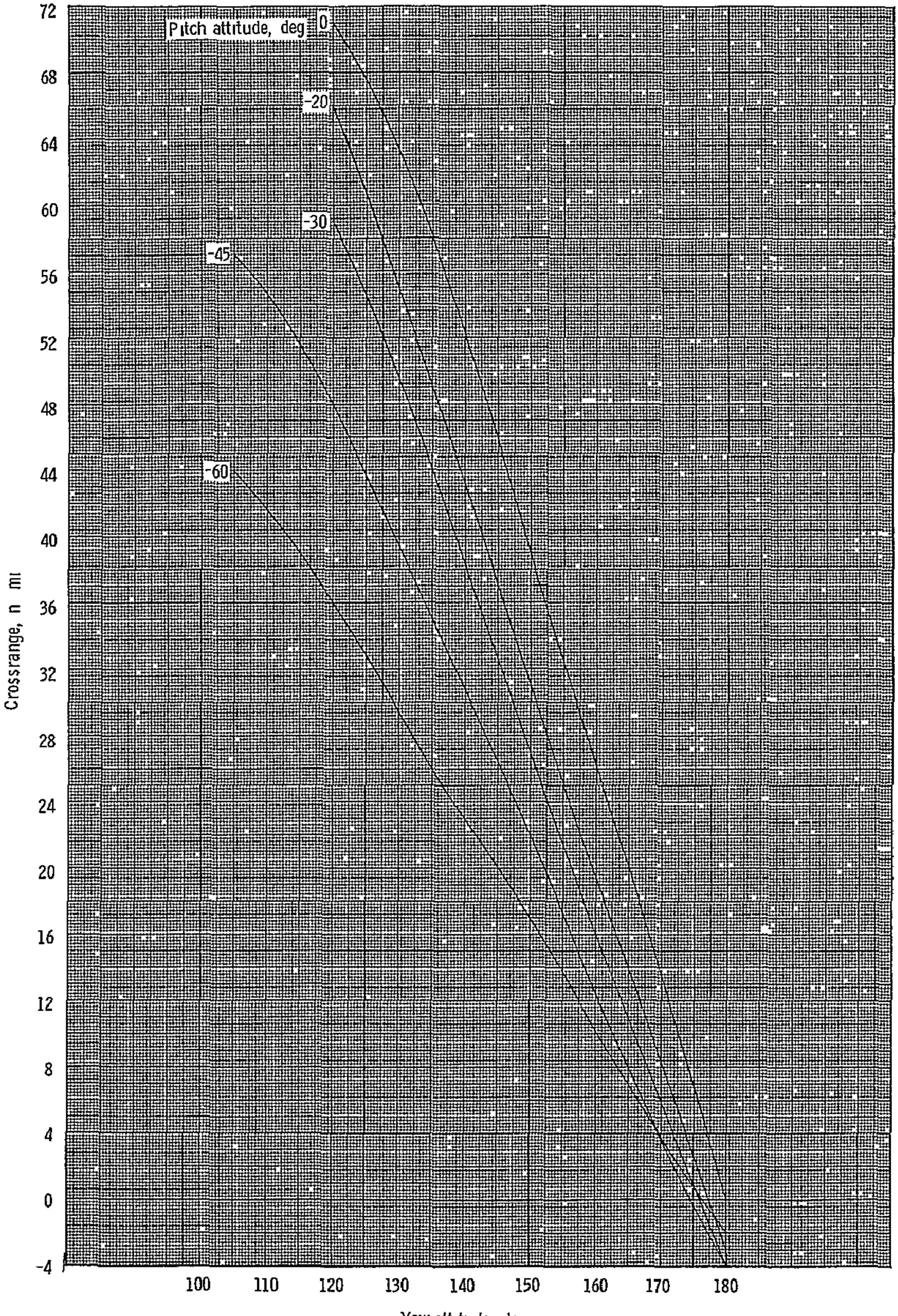
Figure 7 - 85/150 elliptical orbit with burn at apogee for various burn attitudes with downrange or crossrange versus yaw attitudes for various pitches



NASA MSC-FOD
MISSION PLANNING & ANALYSIS DIVISION
FLIGHT ANALYSIS BRANCH
Plot No 17109b
Date March 23, 1966 DPS

(a) ΔV = 400 fps

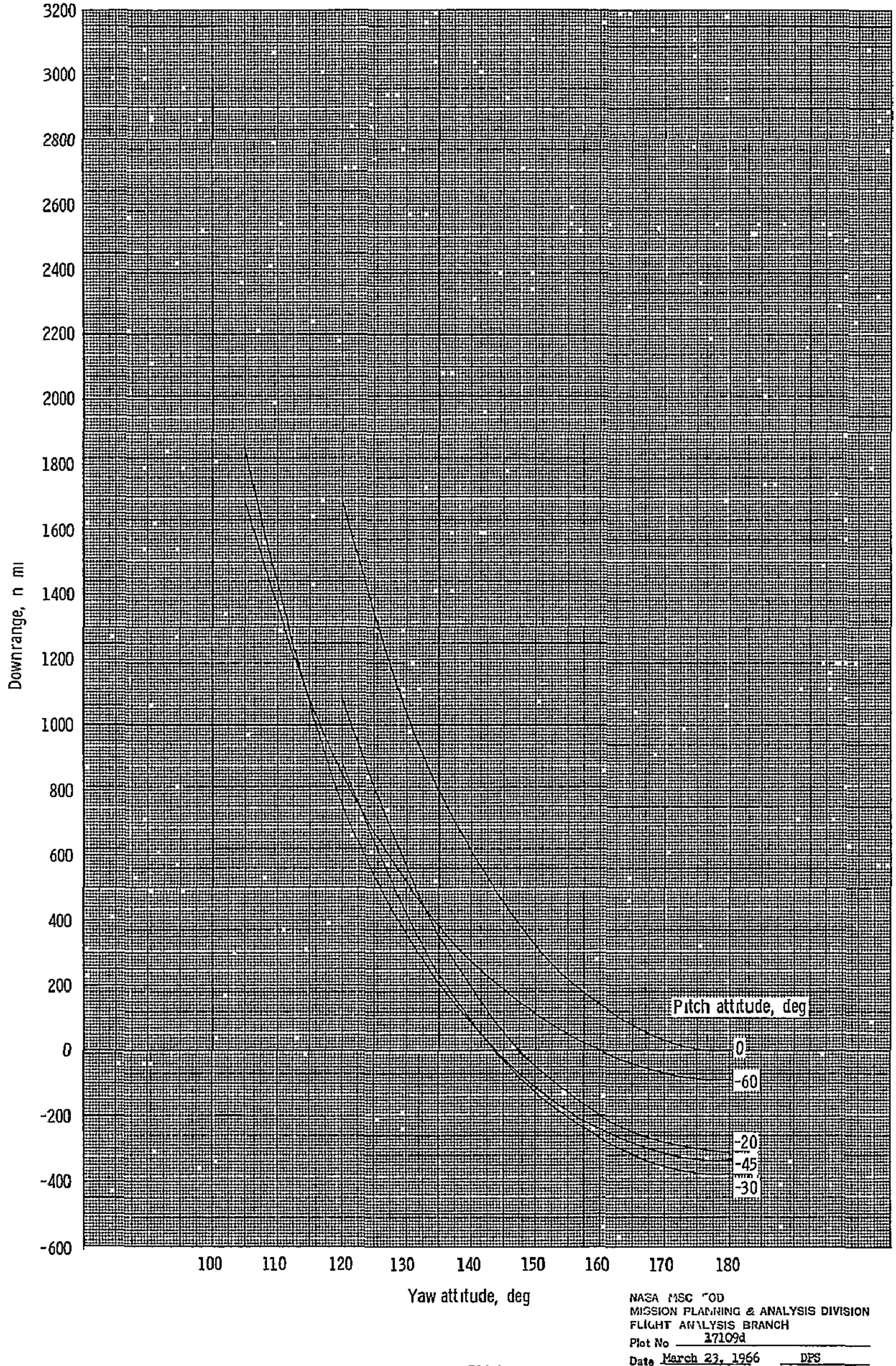
Figure 7 - Continued.



NASA MSC FOD
MISSION PLANNING & ANALYSIS DIVISION
FLIGHT ANALYSIS BRANCH
Plot No 17109c
Date March 23, 1966 DPS

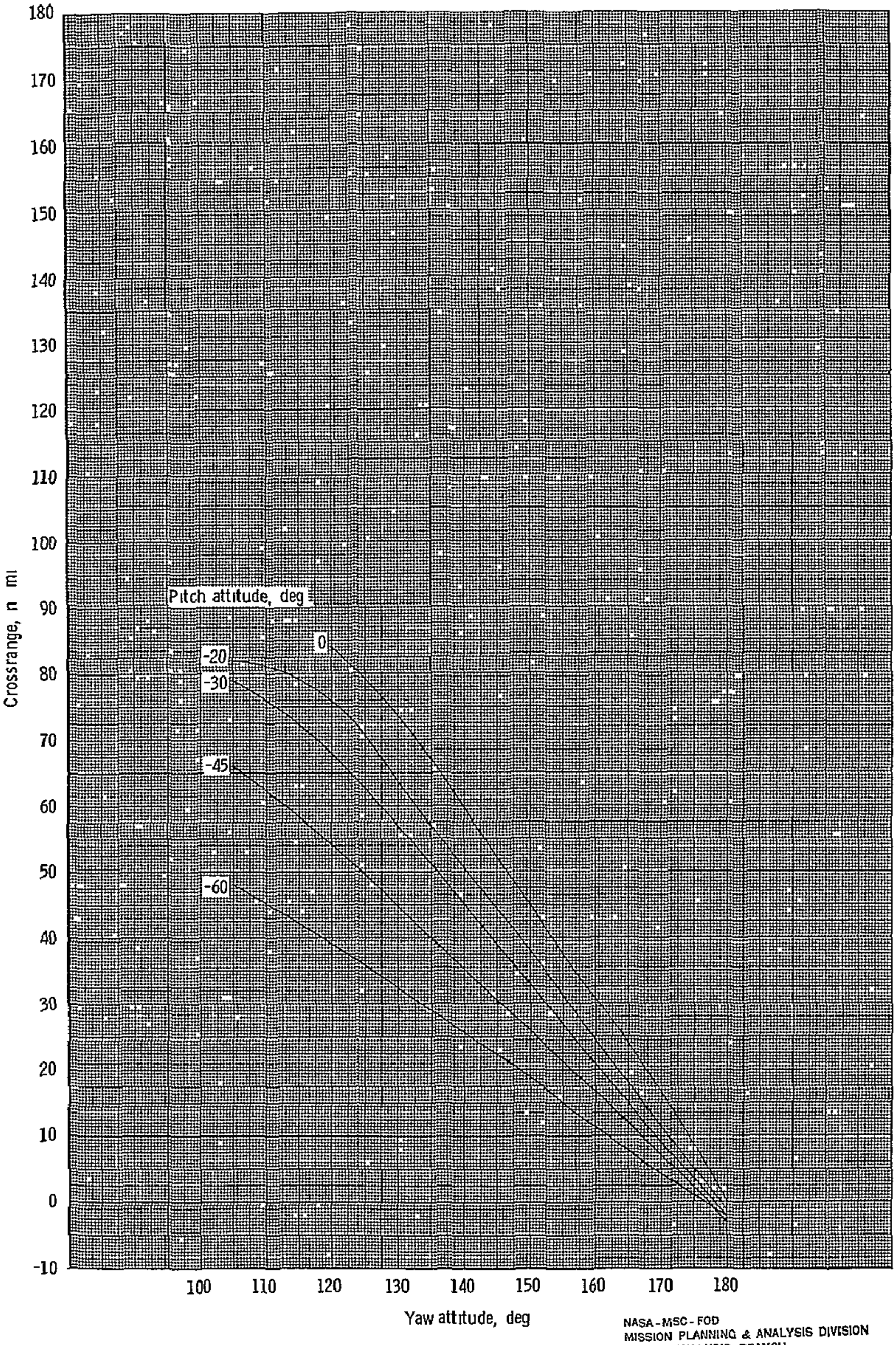
(b) ΔV = 500 fps.

Figure 7 - Continued



(b) ΔV = 500 fps

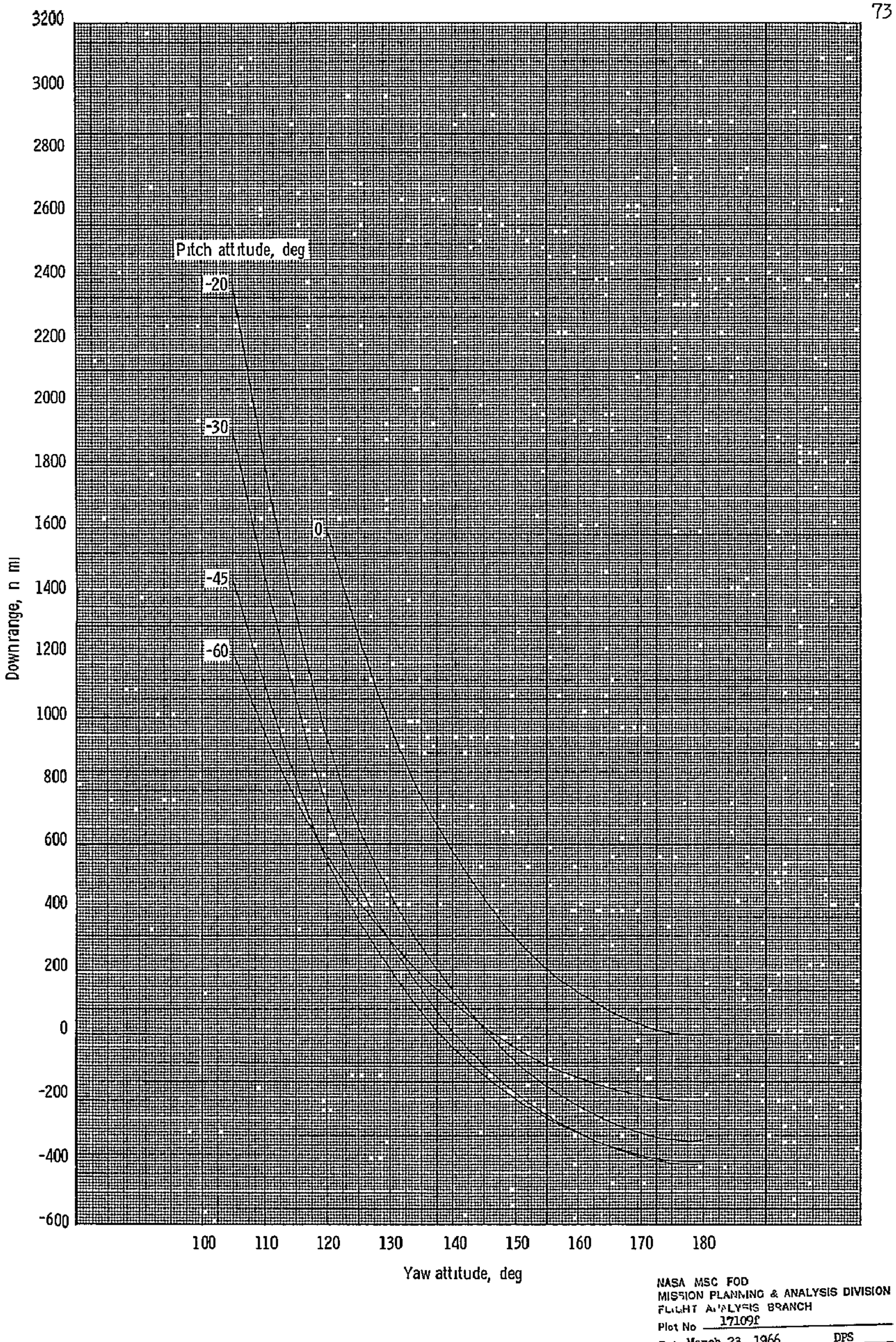
Figure 7. - Continued.



NASA-MSC-FOD
MISSION PLANNING & ANALYSIS DIVISION
FLIGHT ANALYSIS BRANCH
Plot No 17109e
Date March 23, 1966 DPS

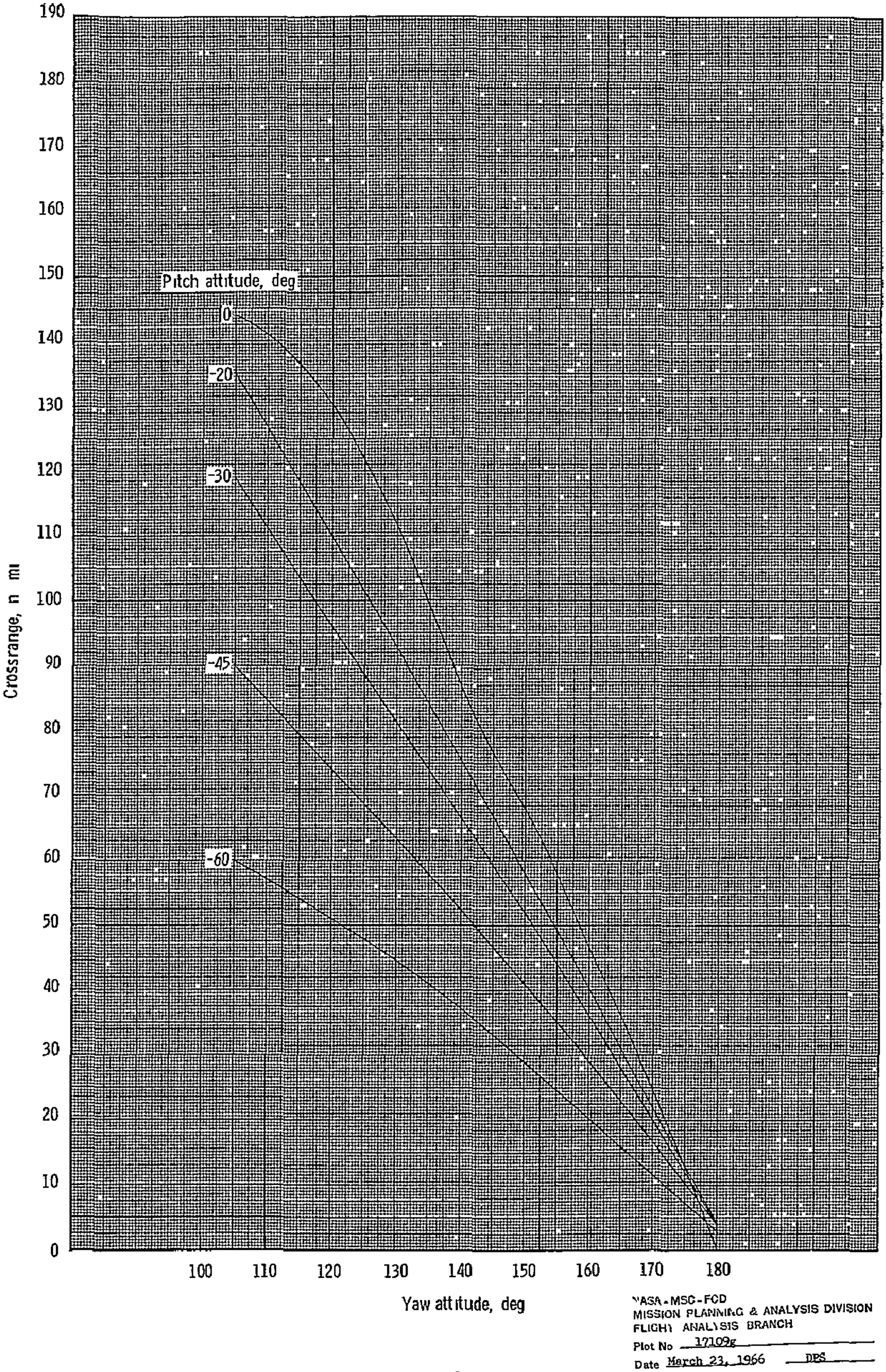
(c) ΔV = 600 fps.

Figure 7 - Continued



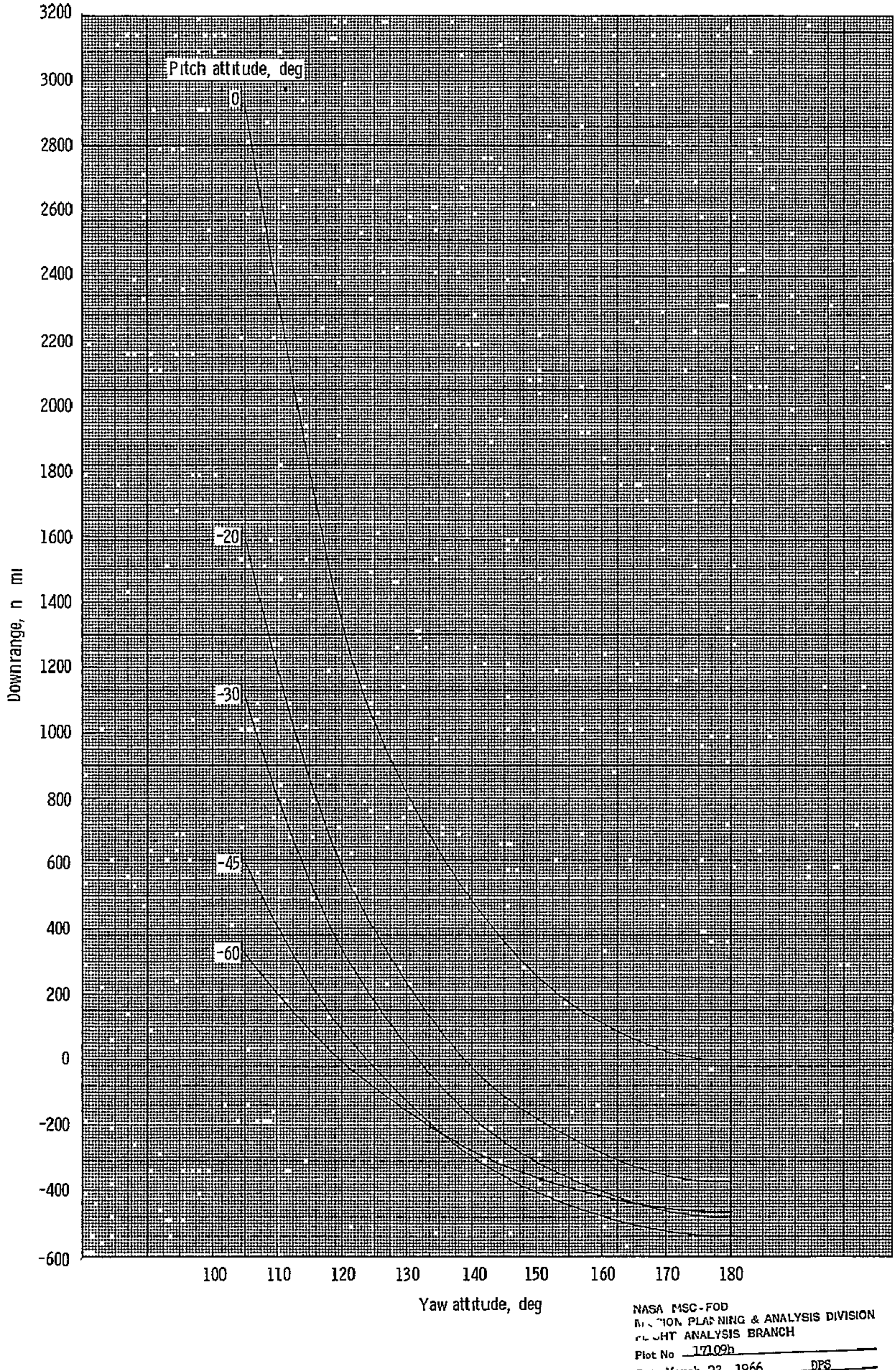
(c) ΔV = 600 fps.

Figure 7. - Continued.



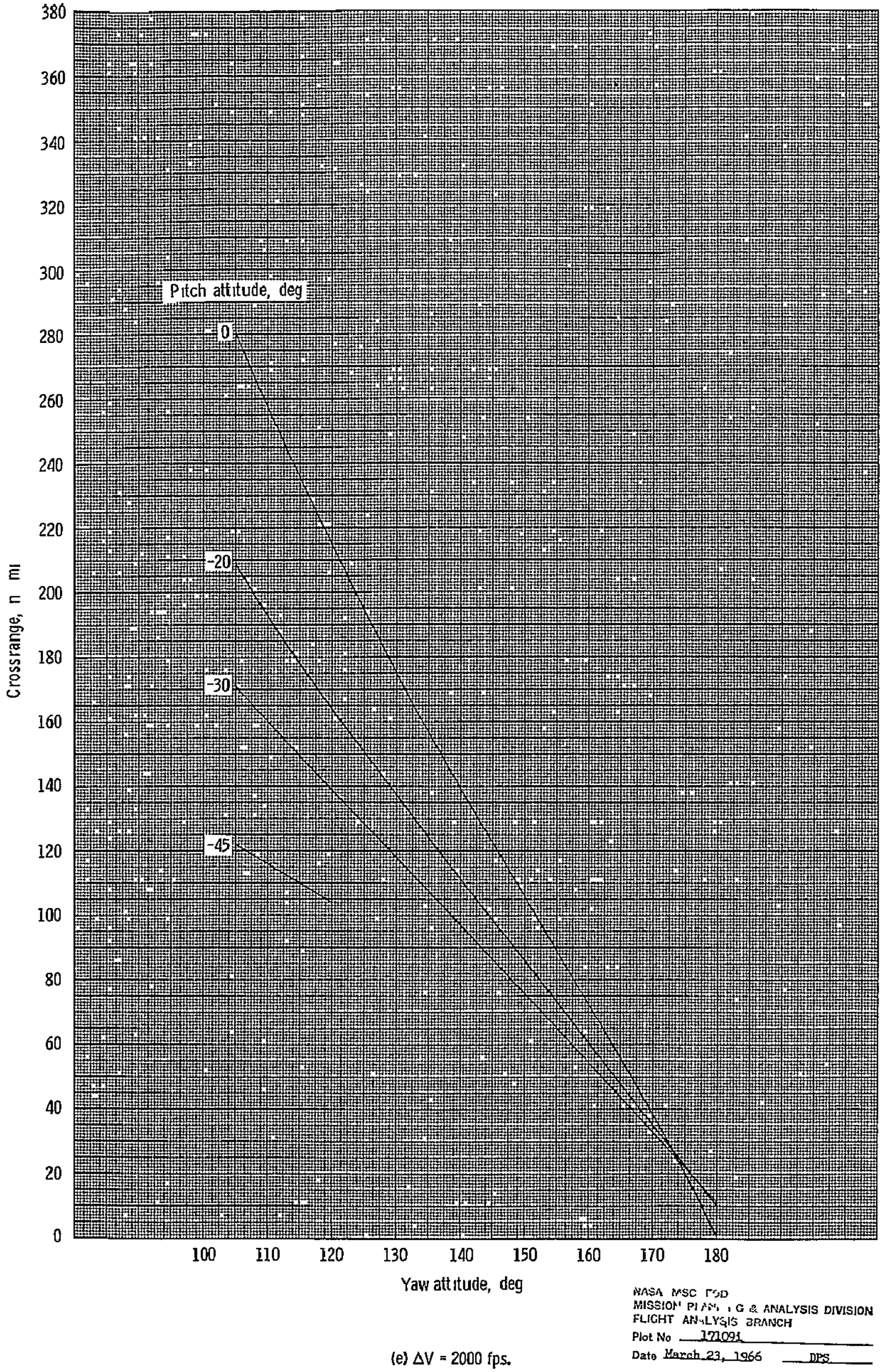
(d) ΔV 1000 fps

Figure 7. - Continued.



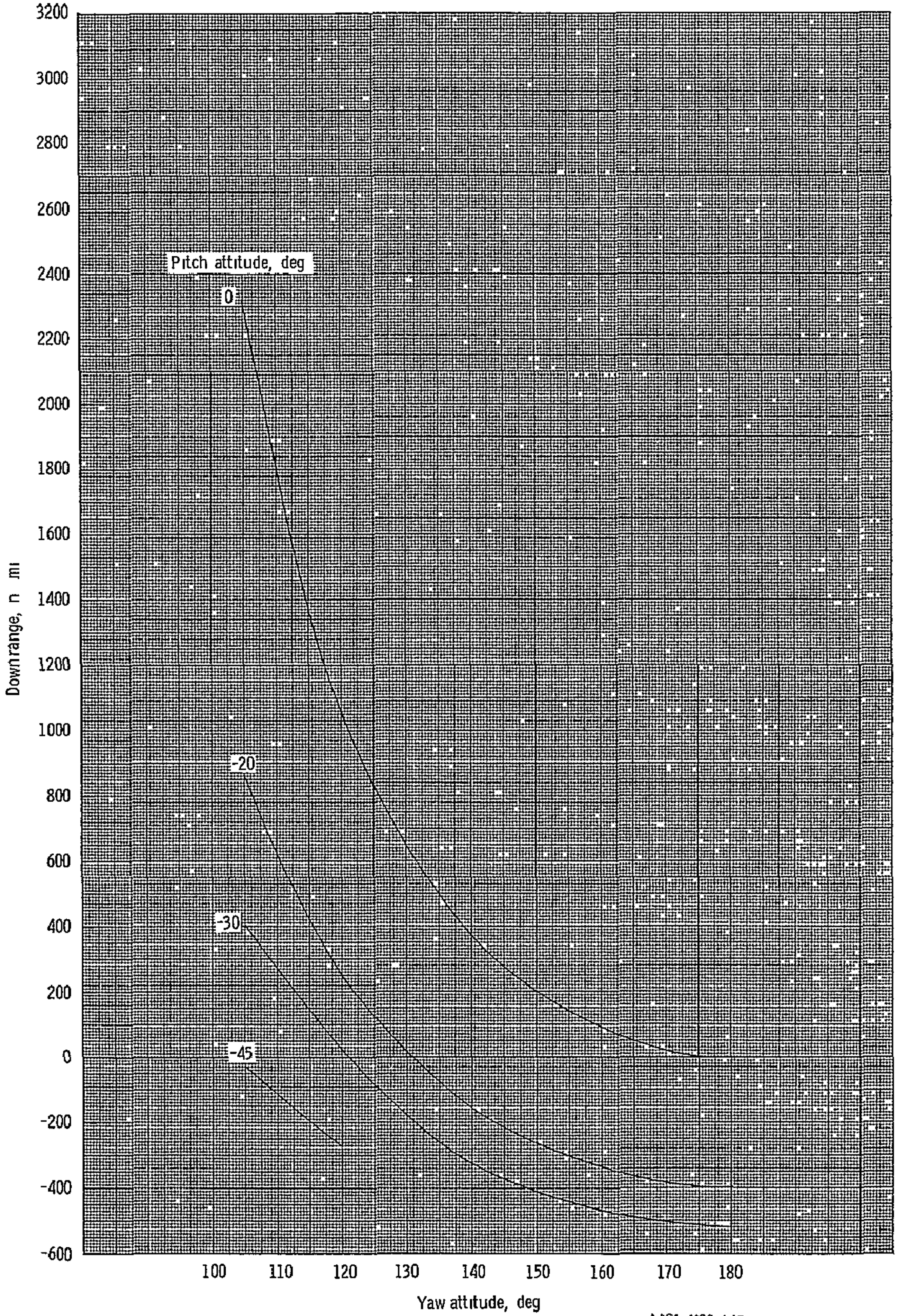
(d) $\Delta V = 1000$ fps

Figure 7 - Continued.



(e) ΔV = 2000 fps.

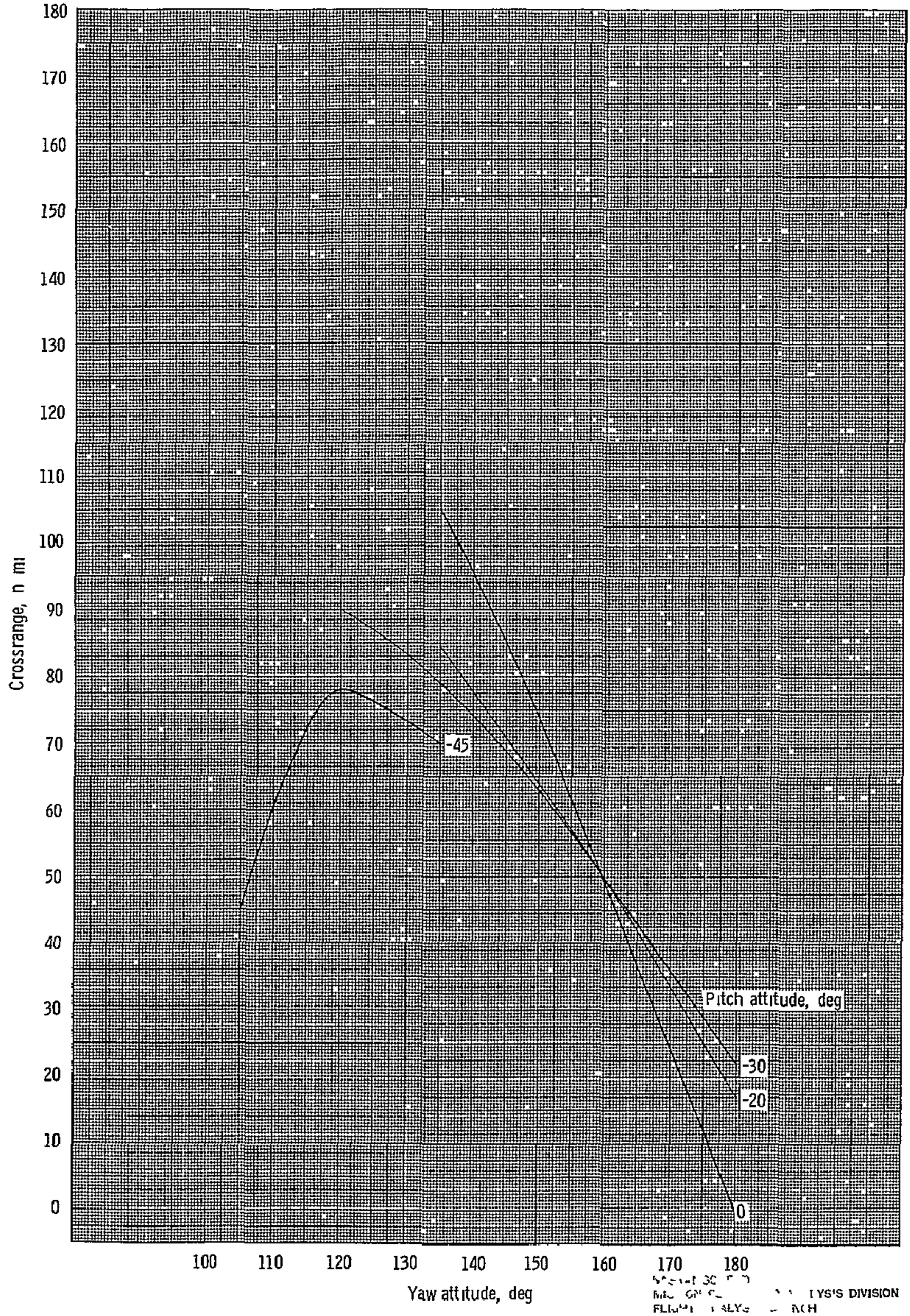
Figure 7 - Continued.



NASA MSC FOD
MISSION PLANNING & ANALYSIS DIVISION
FLIGHT ANALYSIS BRANCH
Plot No 171091
Date March 23, 1966 DPS

(e) ΔV = 2000 fps

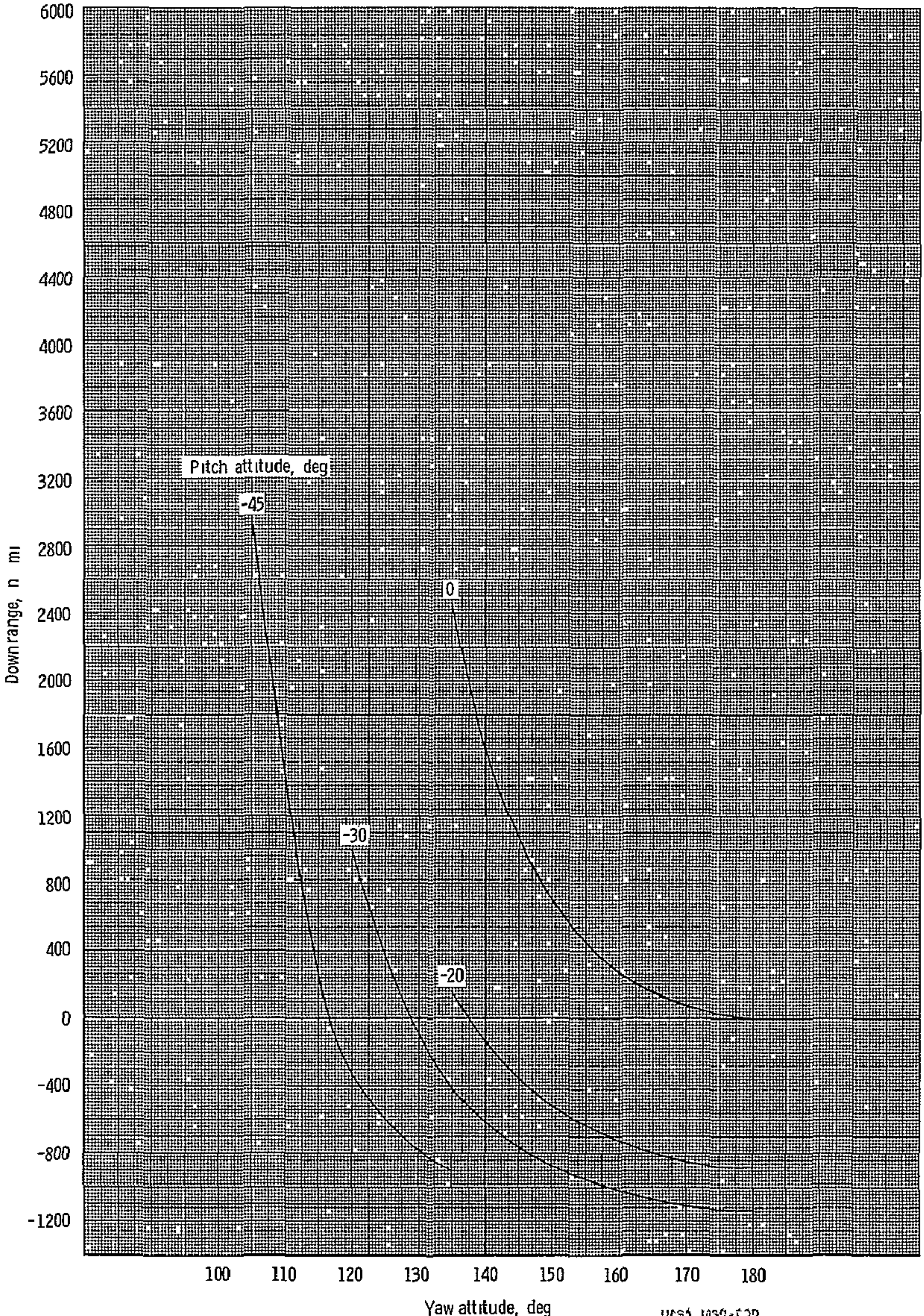
Figure 7 - Concluded.



YS'S DIVISION
Plot No 17110a
Date March 23, 1966 DPS

(a) ΔV = 1000 fps.

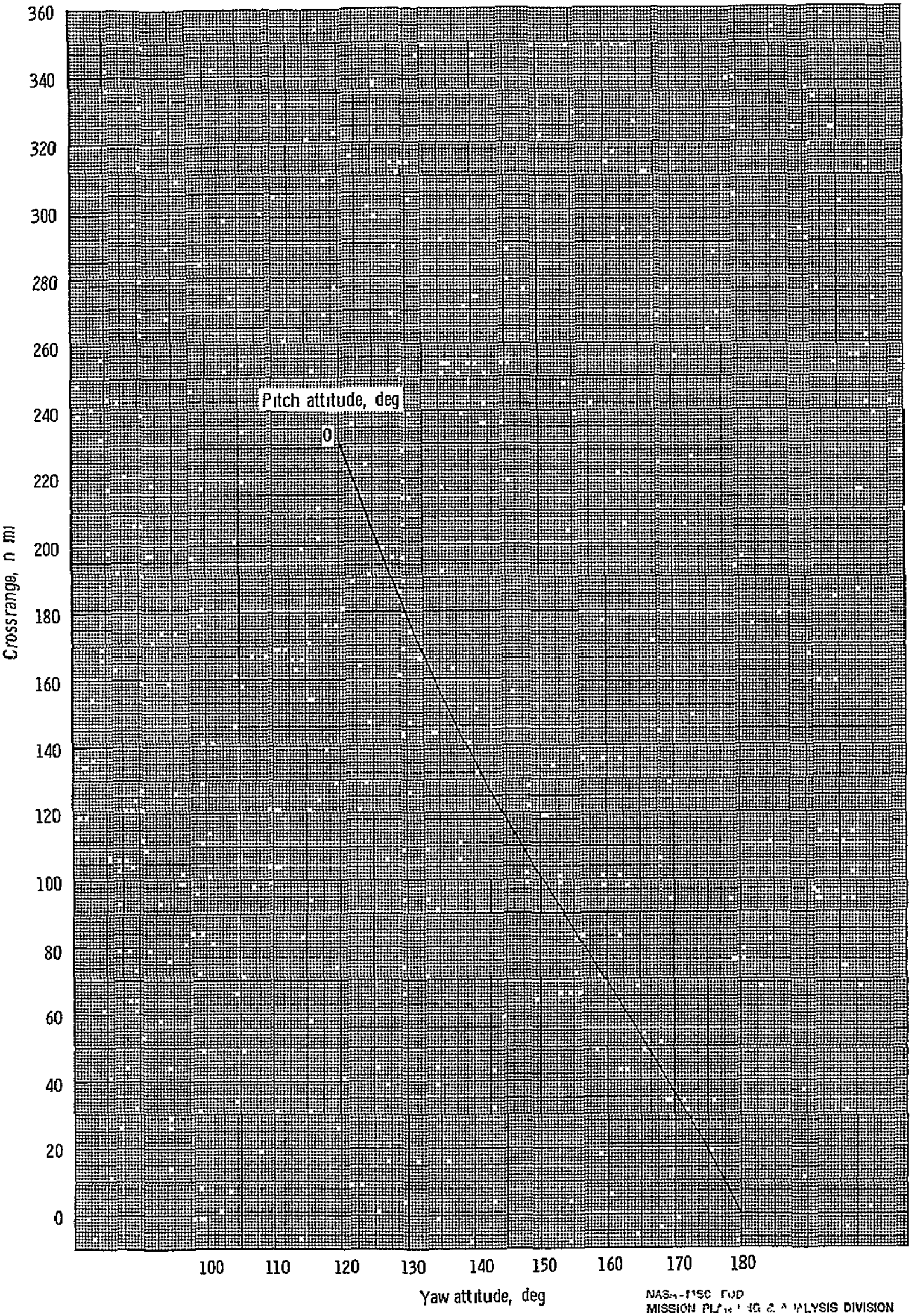
Figure 8 - 85/400 elliptical orbit with burn at perigee for various burn attitudes with downrange or crossrange versus yaw attitudes for various pitches



NASA MSC-FOD
MISSION PLANNING & ANALYSIS DIVISION
FLIGHT ANALYSIS BRANCH
Plot No 17110b
Date March 23, 1966 DPS

(a) ΔV = 1000 fps.

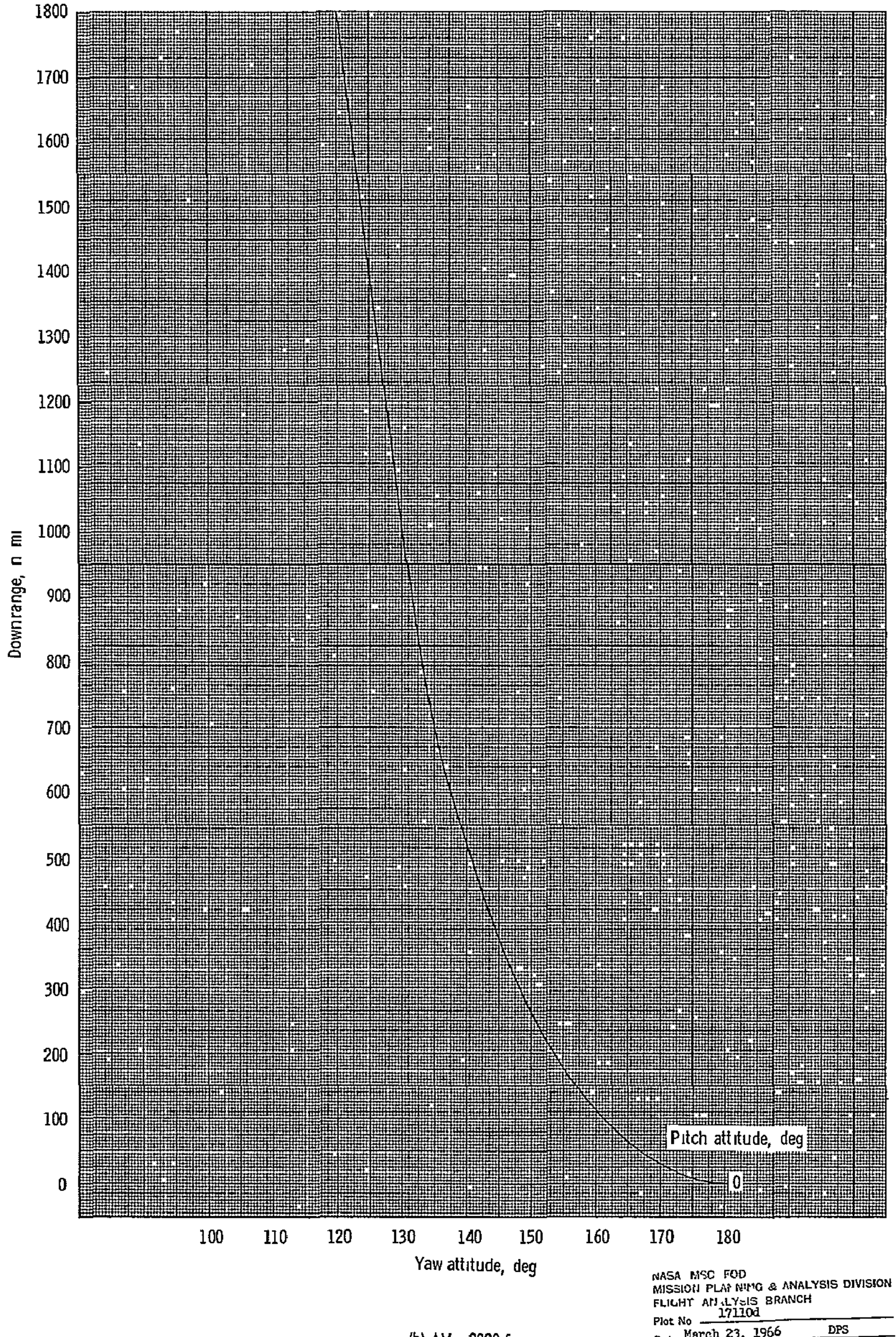
Figure 8. - Continued.



NASA-MSC FOD
MISSION PLANNING & ANALYSIS DIVISION
FLIGHT ANALYSIS BRANCH
Plot No 17110c
Date March 23, 1966 DPS

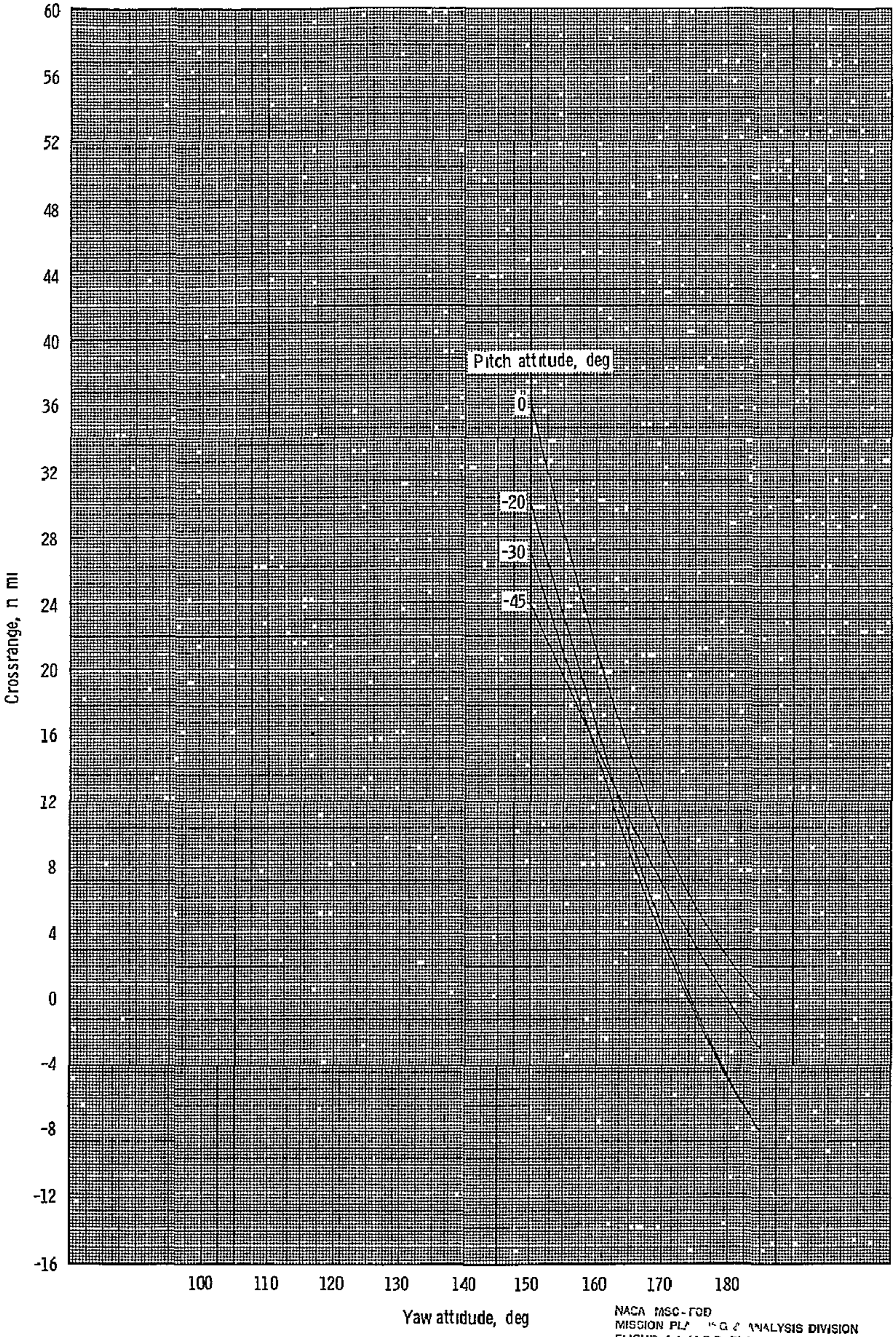
(b) ΔV = 2000 fps.

Figure 8 - Continued.



(b) ΔV = 2000 fps

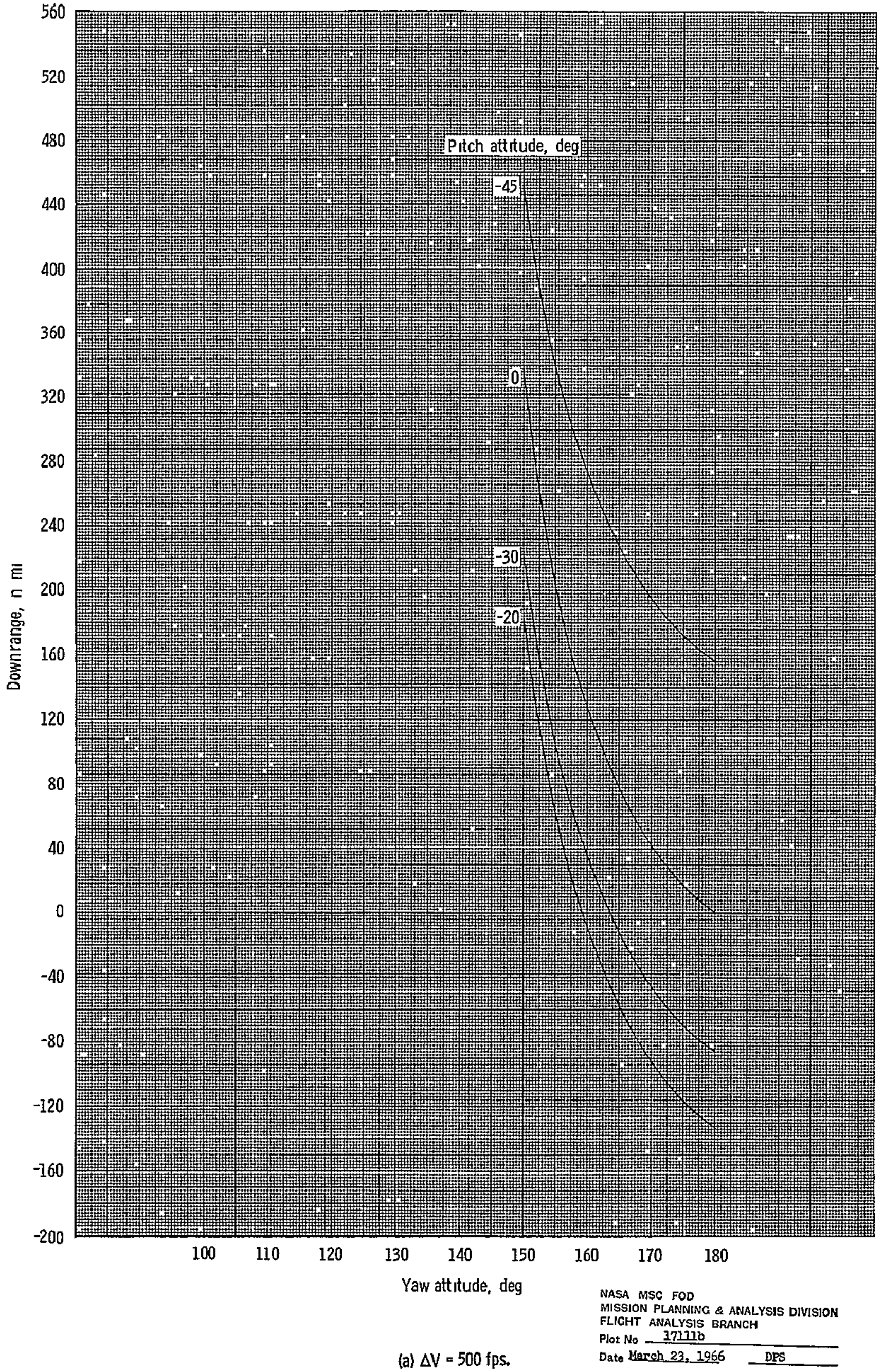
Figure 8 - Concluded



NASA MSC-FOD
MISSION PL... G & ANALYSIS DIVISION
FLIGHT A...LYS... BRANCH
Plot No 17111a
Date March 23, 1966 DPS

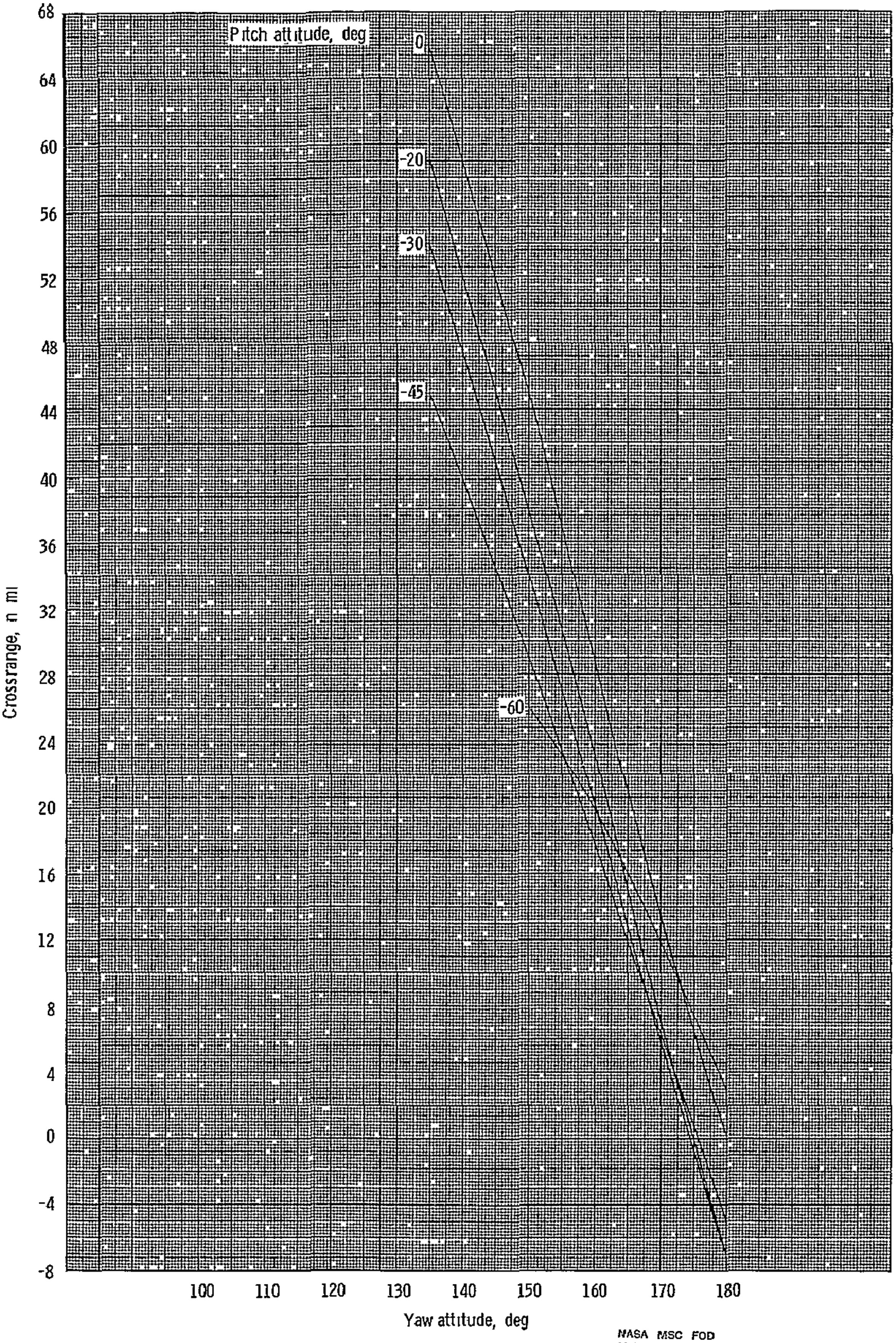
(a) ΔV = 500 fps.

Figure 9. - 85/400 elliptical orbit with burn at apogee for various burn attitudes with downrange or crossrange versus yaw attitudes for various pitches



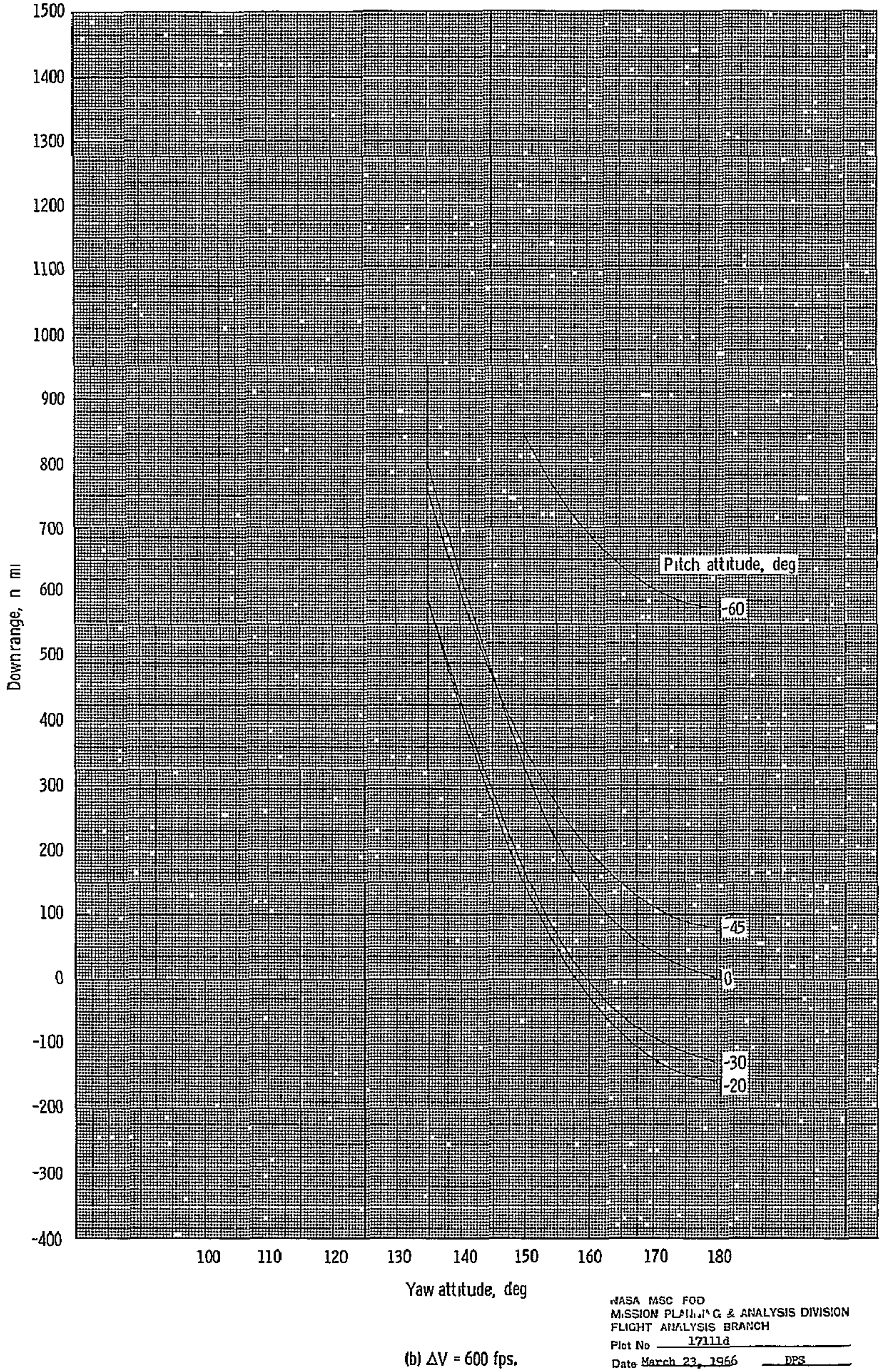
(a) ΔV = 500 fps.

Figure 9 - Continued.



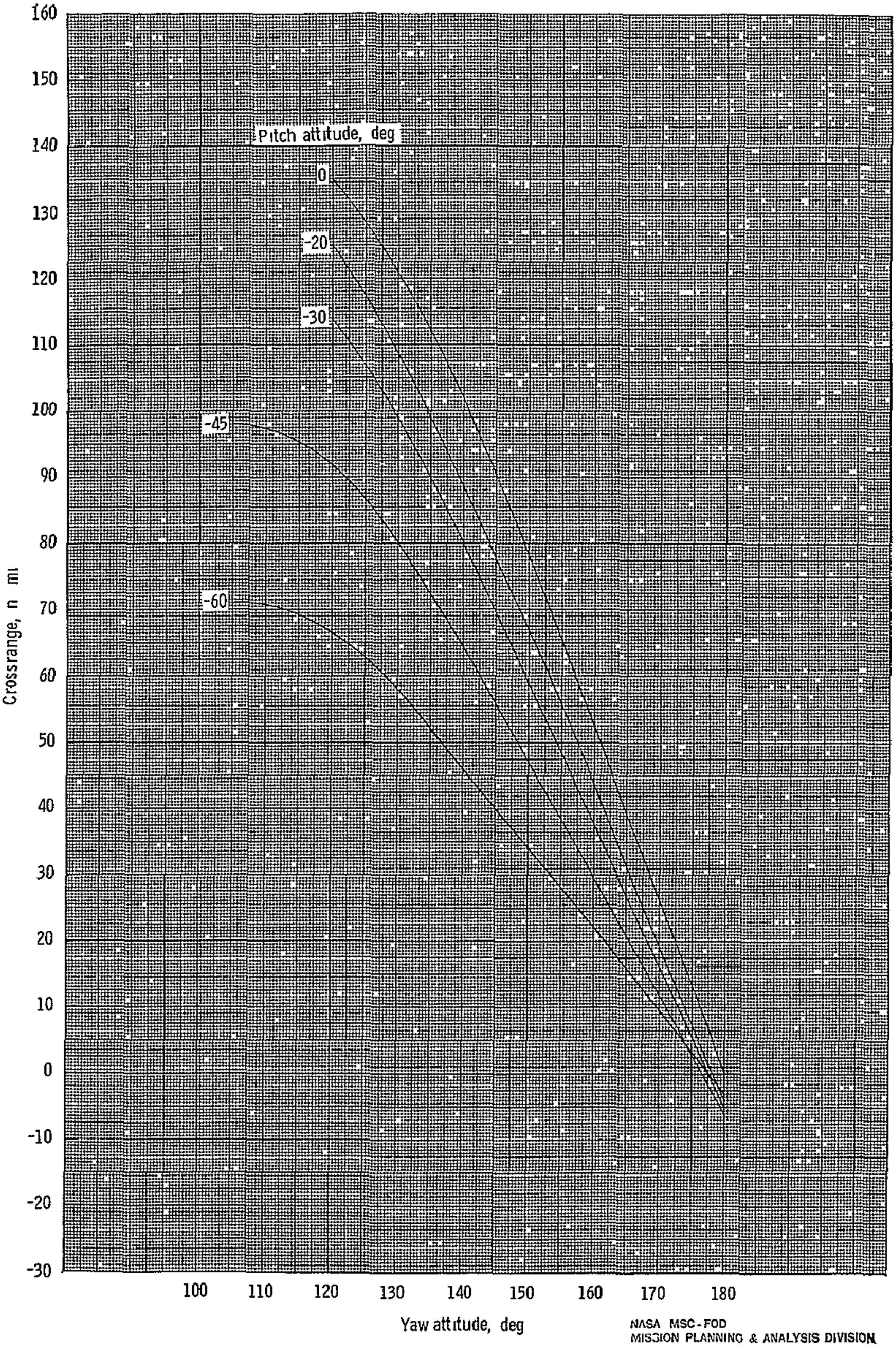
(b) ΔV = 600 fps.

Figure 9 - Continued



(b) ΔV = 600 fps.

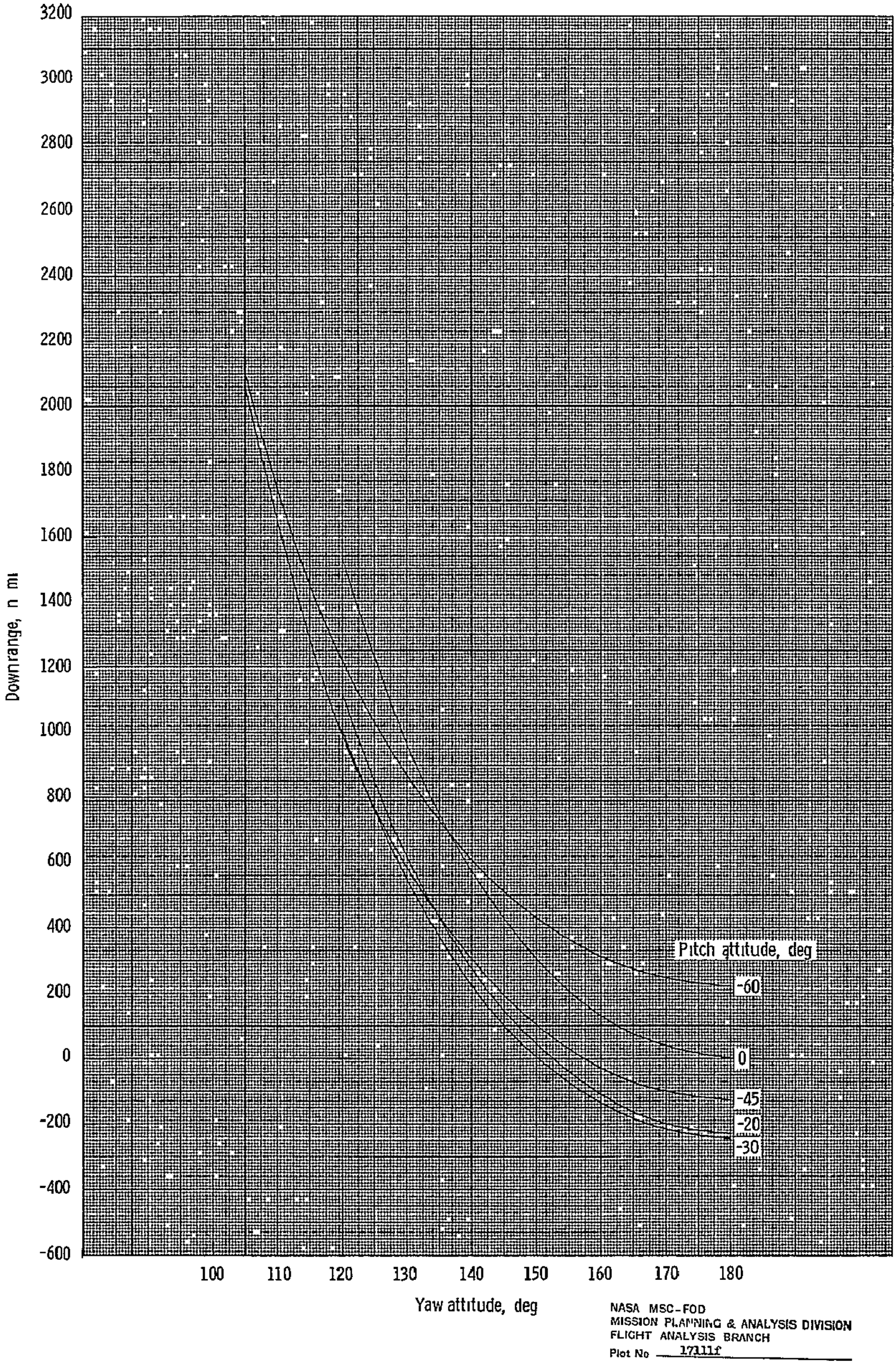
Figure 9. - Continued.



NASA MSC-FOD
MISSION PLANNING & ANALYSIS DIVISION
FLIGHT ANALYSIS BRANCH
Plot No 17111e
Date March 23, 1966 DPS

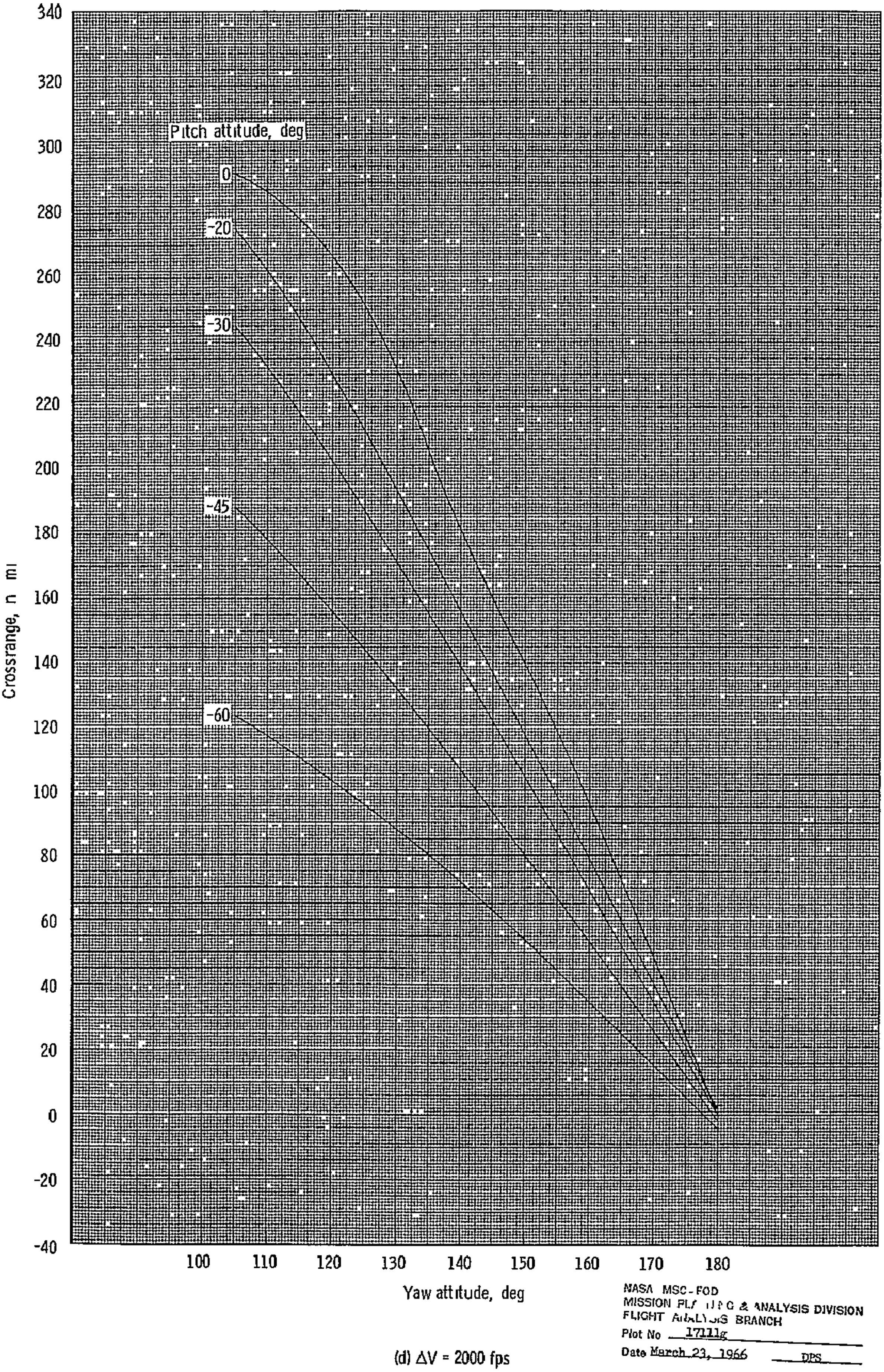
(c) ΔV = 1000 fps.

Figure 9 - Continued.



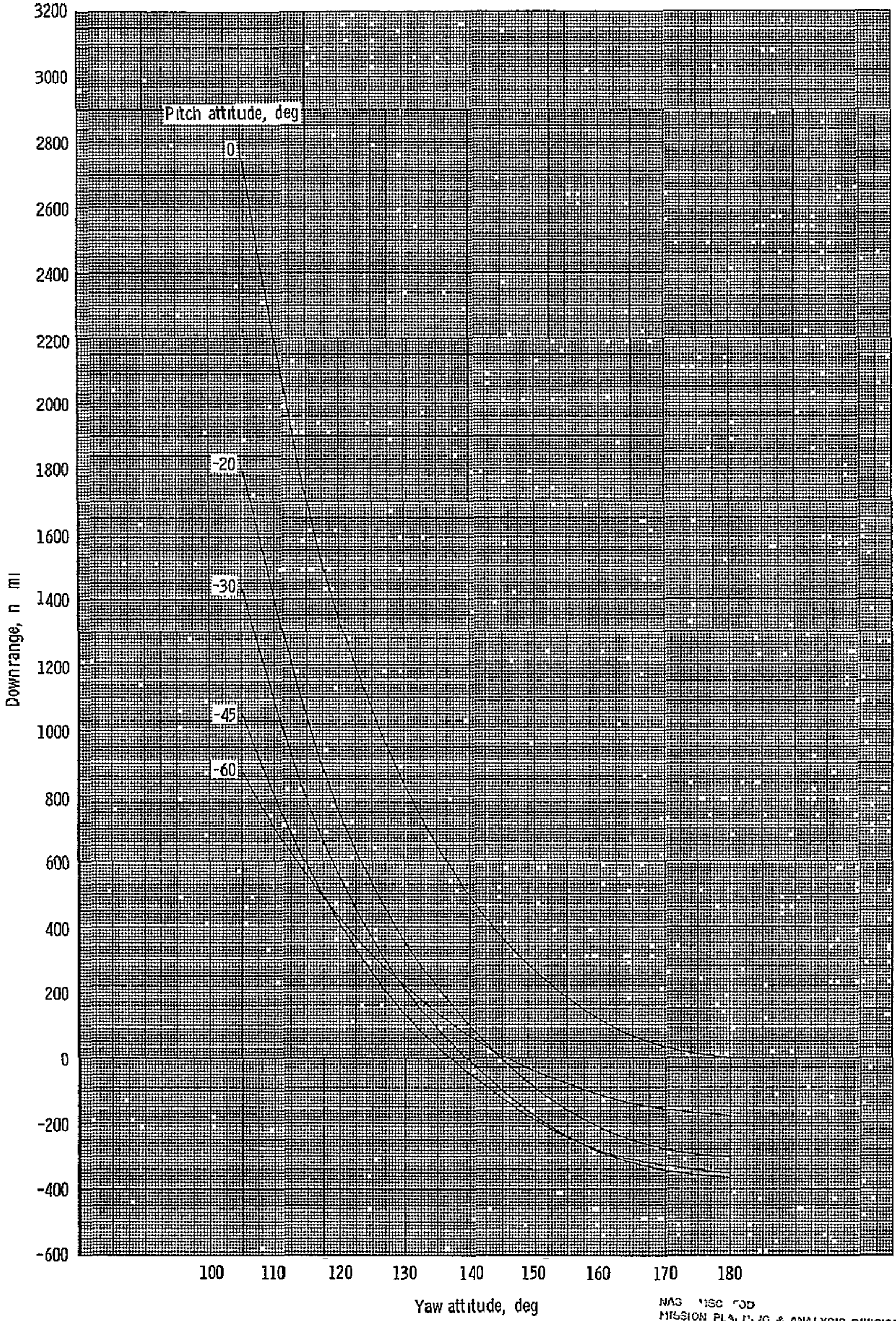
(c) ΔV = 1000 fps.

Figure 9. - Continued.



(d) ΔV = 2000 fps

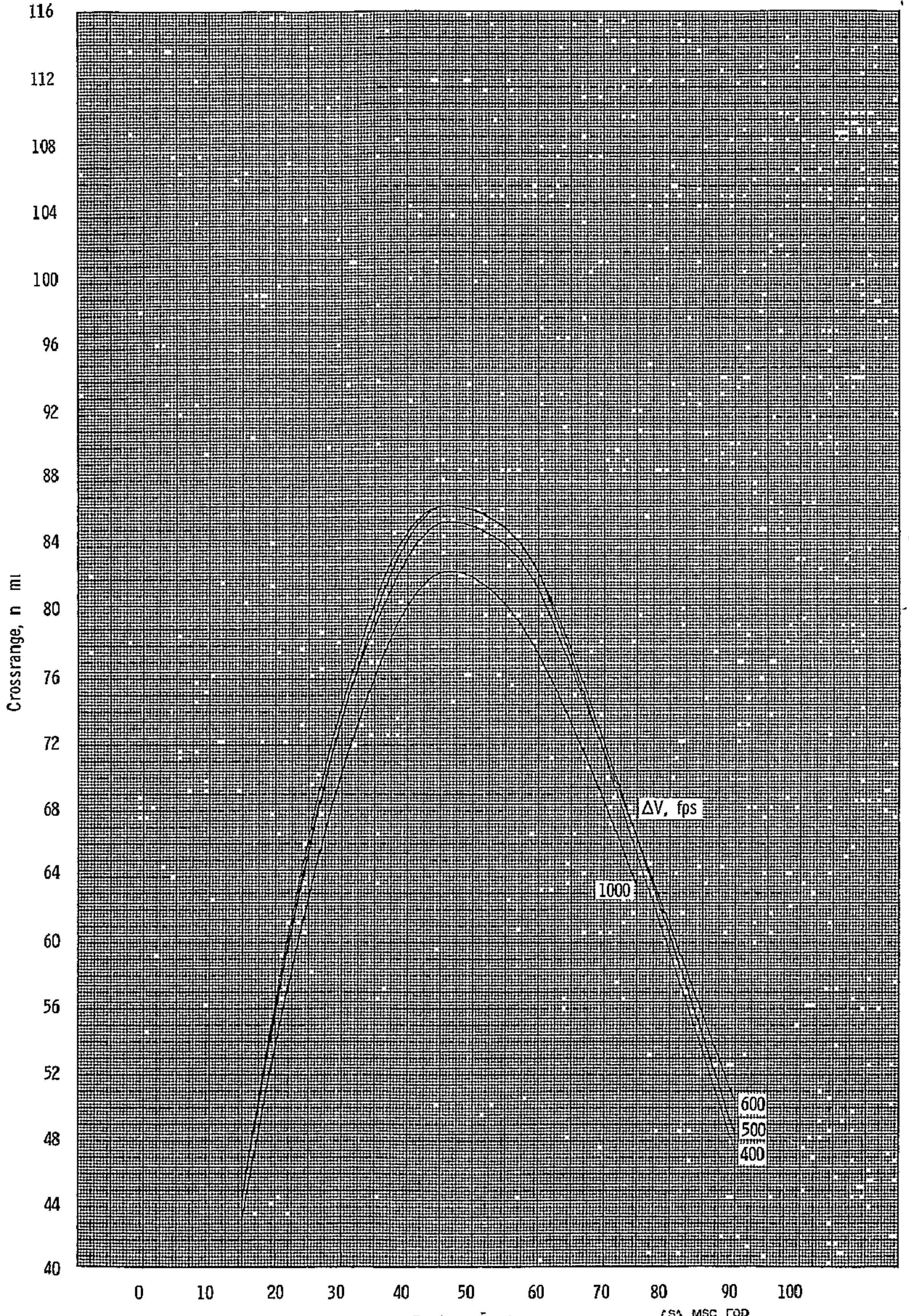
Figure 9 - Continued



NASA MSC FOD
MISSION PLANNING & ANALYSIS DIVISION
FLIGHT ANALYSIS BRANCH
Plot No 17111b
Date March 23, 1966 DPS

(d) ΔV = 2000 fps

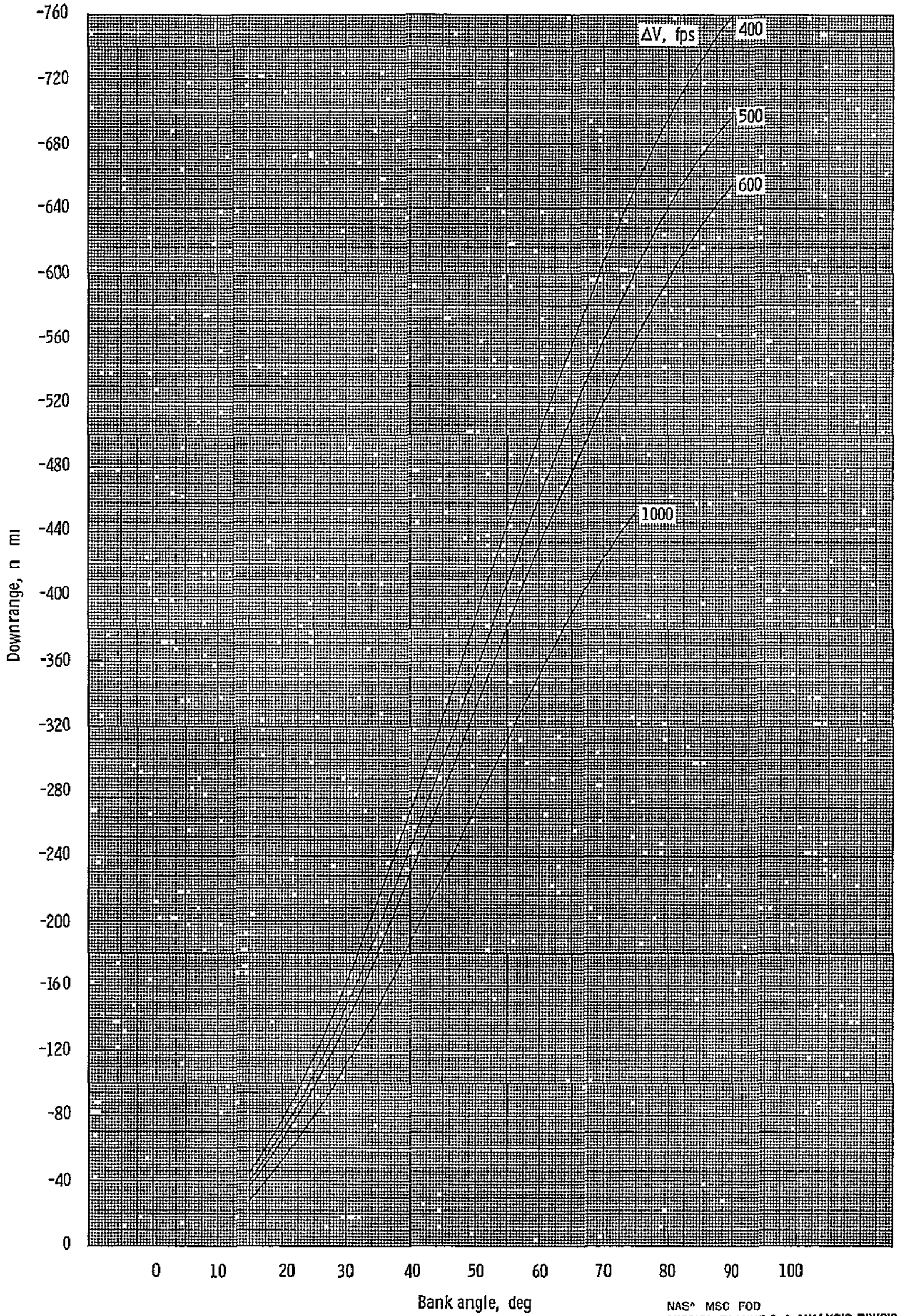
Figure 9 - Concluded.



NASA MSC FOD
MISSION PLANNING & ANALYSIS DIVISION
FLIGHT ANALYSIS BRANCH
No 17112a
Date March 23, 1966 DPS

(a) 85 nautical mile circular orbit.

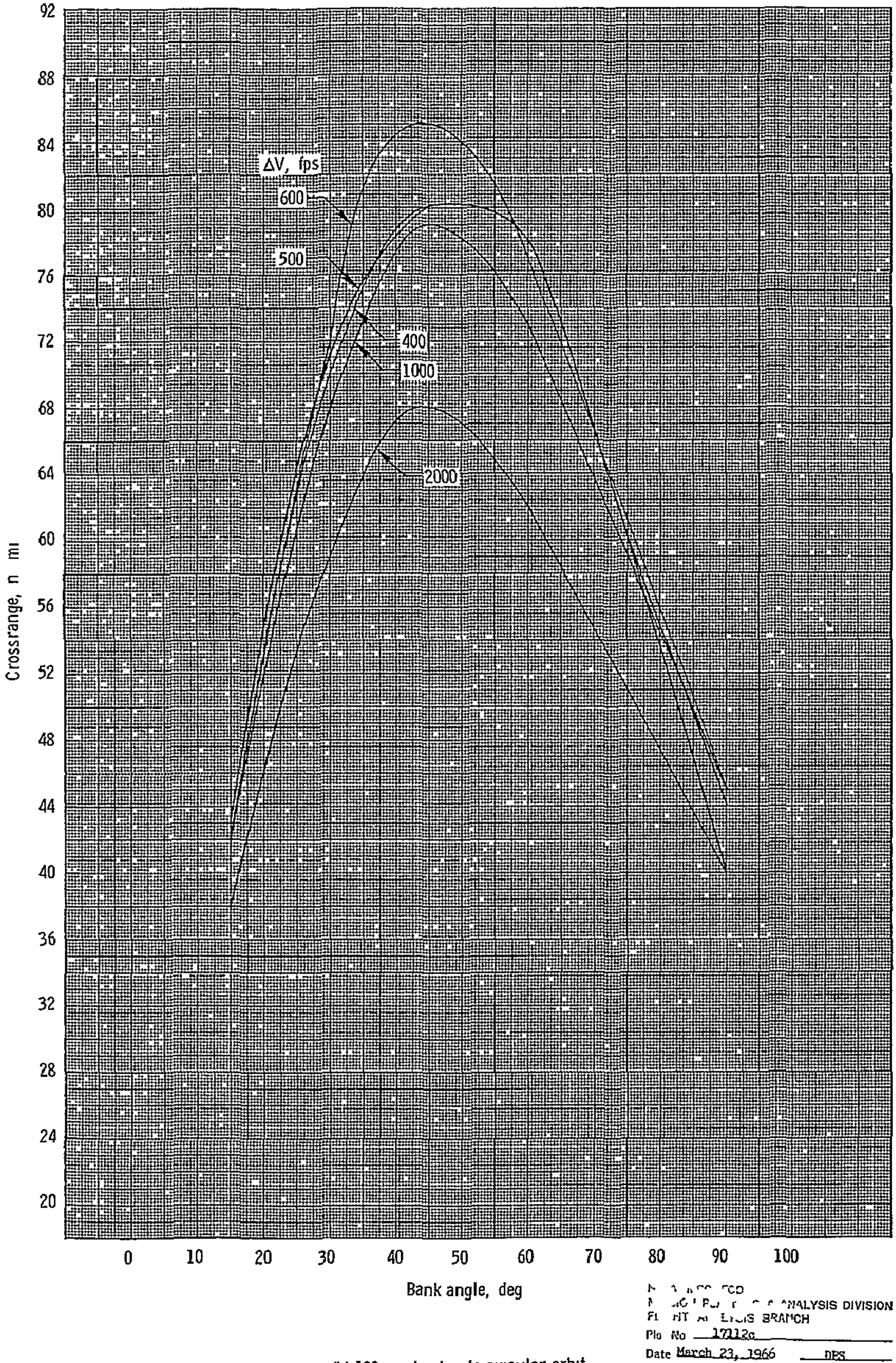
Figure 10 - Bank angle versus crossrange or downrange for various orbital conditions.



NASA MSC FOD
MISSION PLANNING & ANALYSIS DIVISION
FLIGHT ANALYSIS BRANCH
Plot No 17112b
Date March 23, 1966 DPS

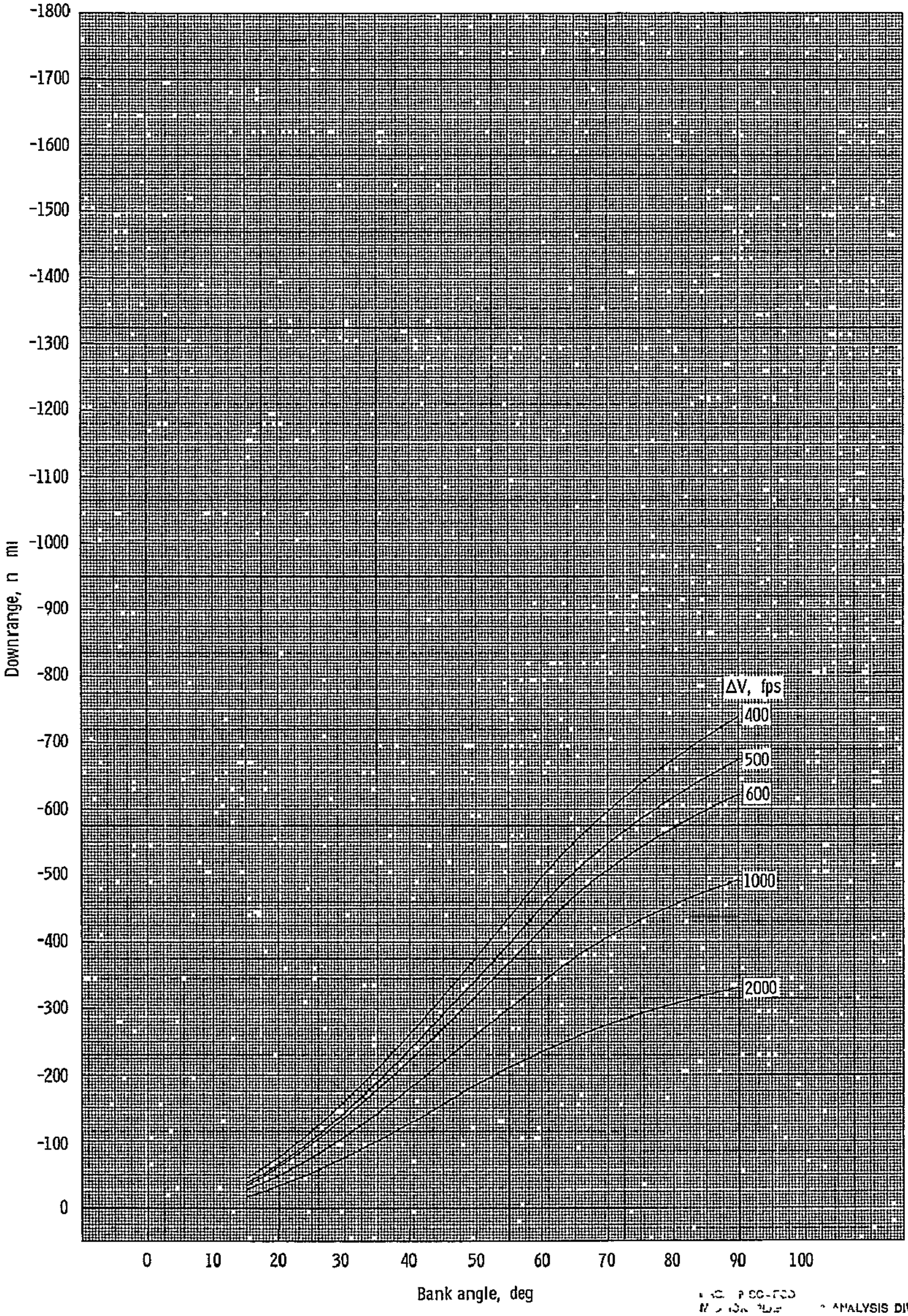
(a) 85 nautical mile circular orbit.

Figure 10 - Continued.



(b) 100 nautical mile circular orbit.

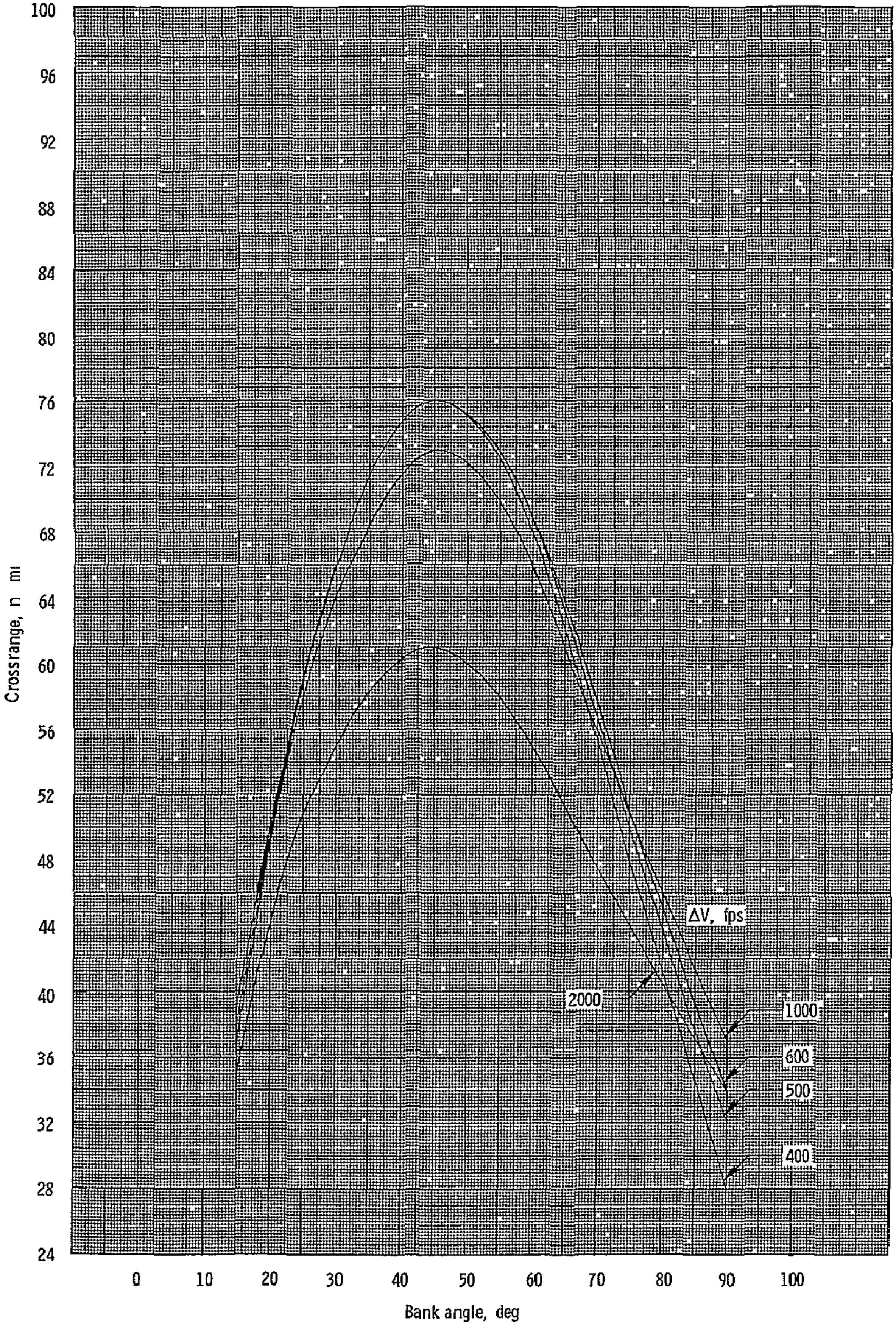
Figure 10 - Continued.



ANALYSIS DIVISION
Plot No 17112a
Date March 23, 1966 DPS

(b) 100 nautical mile circular orbit.

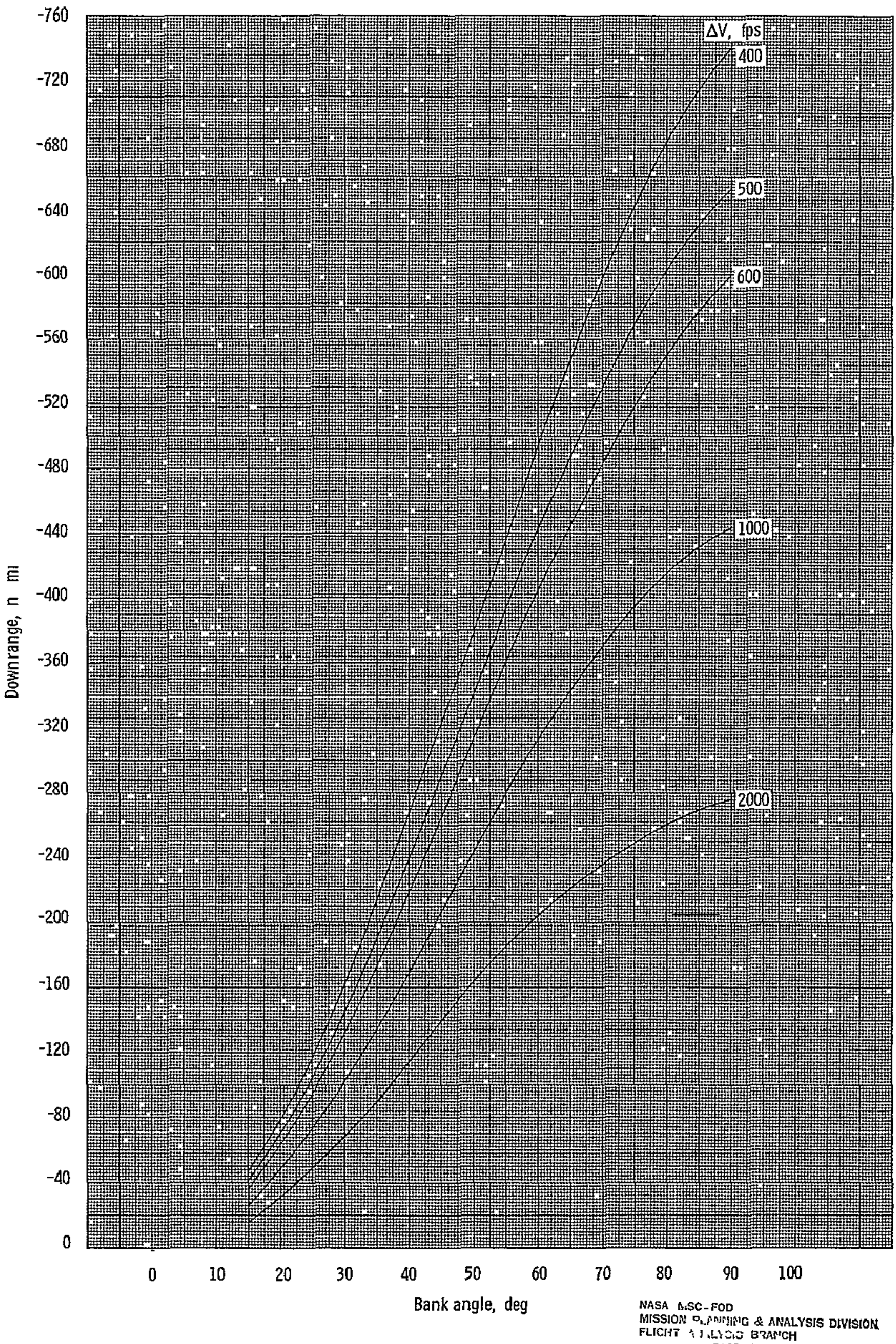
Figure 10 - Continued.



NASA - MSC FOD
MISSION PL[illegible] G & ANALYSIS DIVISION
[illegible]LIGHT ANALYSIS BRANCH
Plot No 17132e
Date March 23, 1966 DPS

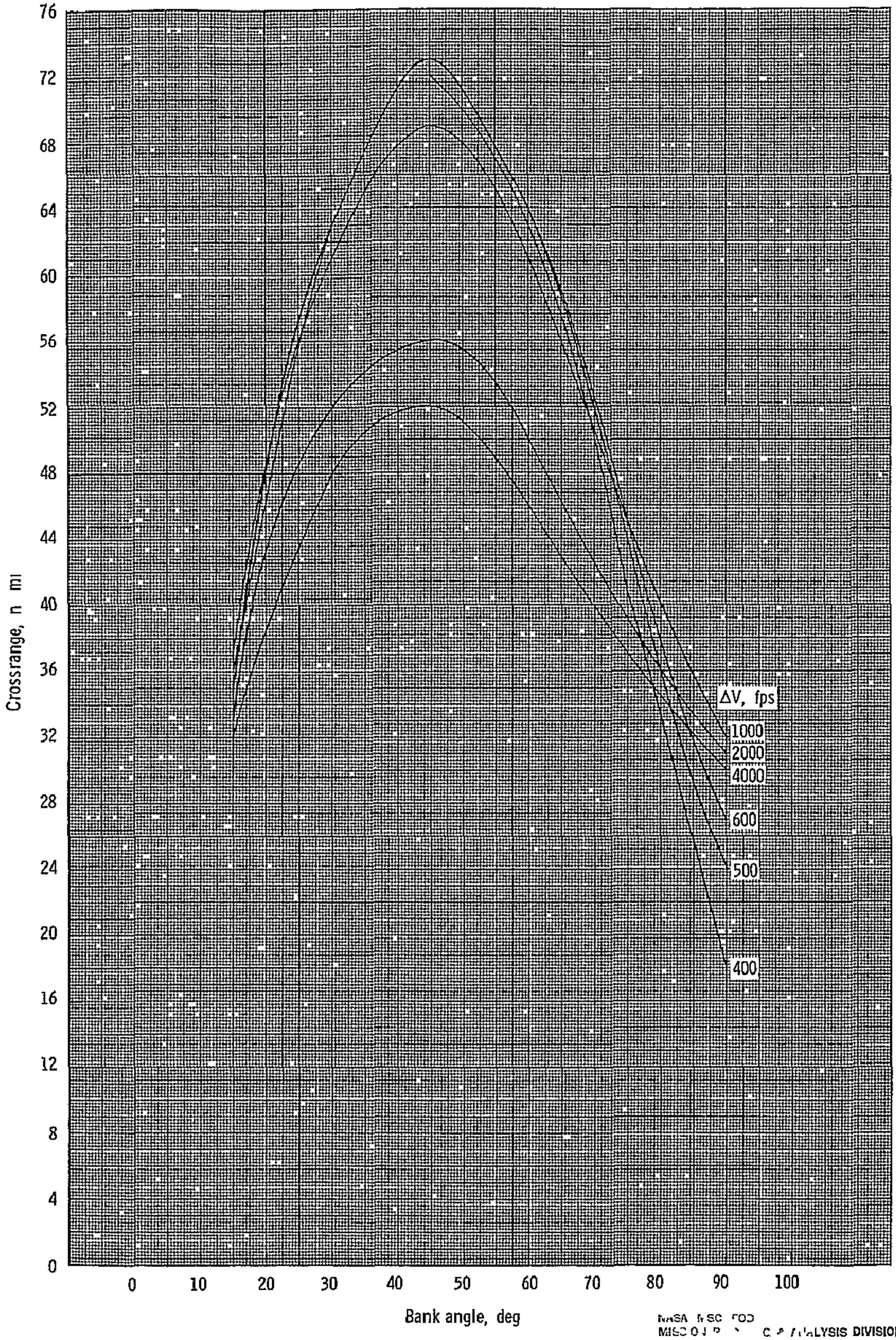
(c) 150 nautical mile circular orbit

Figure 10 - Continued.



(c) 150 nautical mile circular orbit.

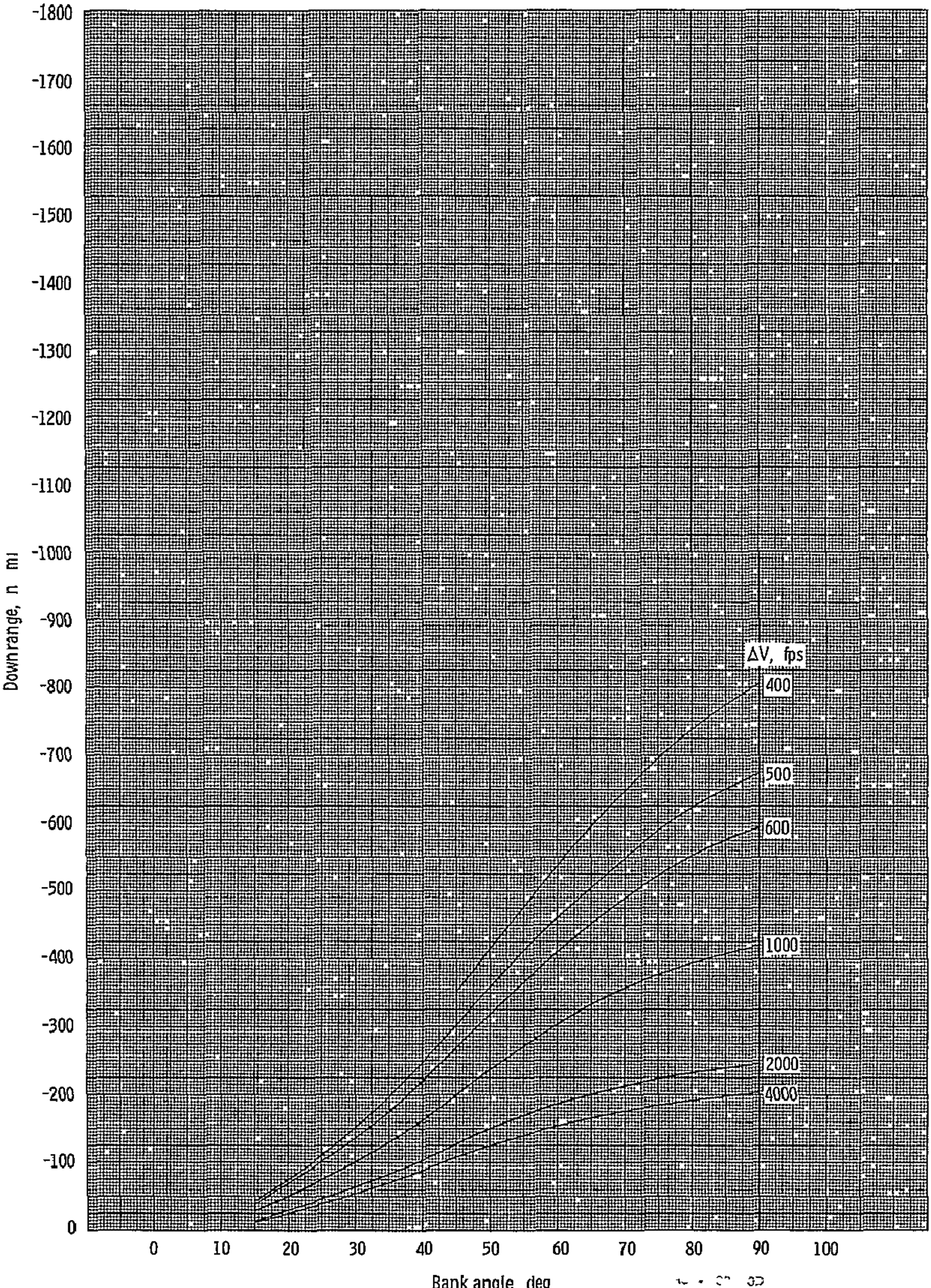
Figure 10 - Continued.



NASA MSC FOD
ANALYSIS DIVISION
BRANCH
Plo No 17112g
Date March 23, 1966 DPS

(d) 200 nautical mile circular orbit.

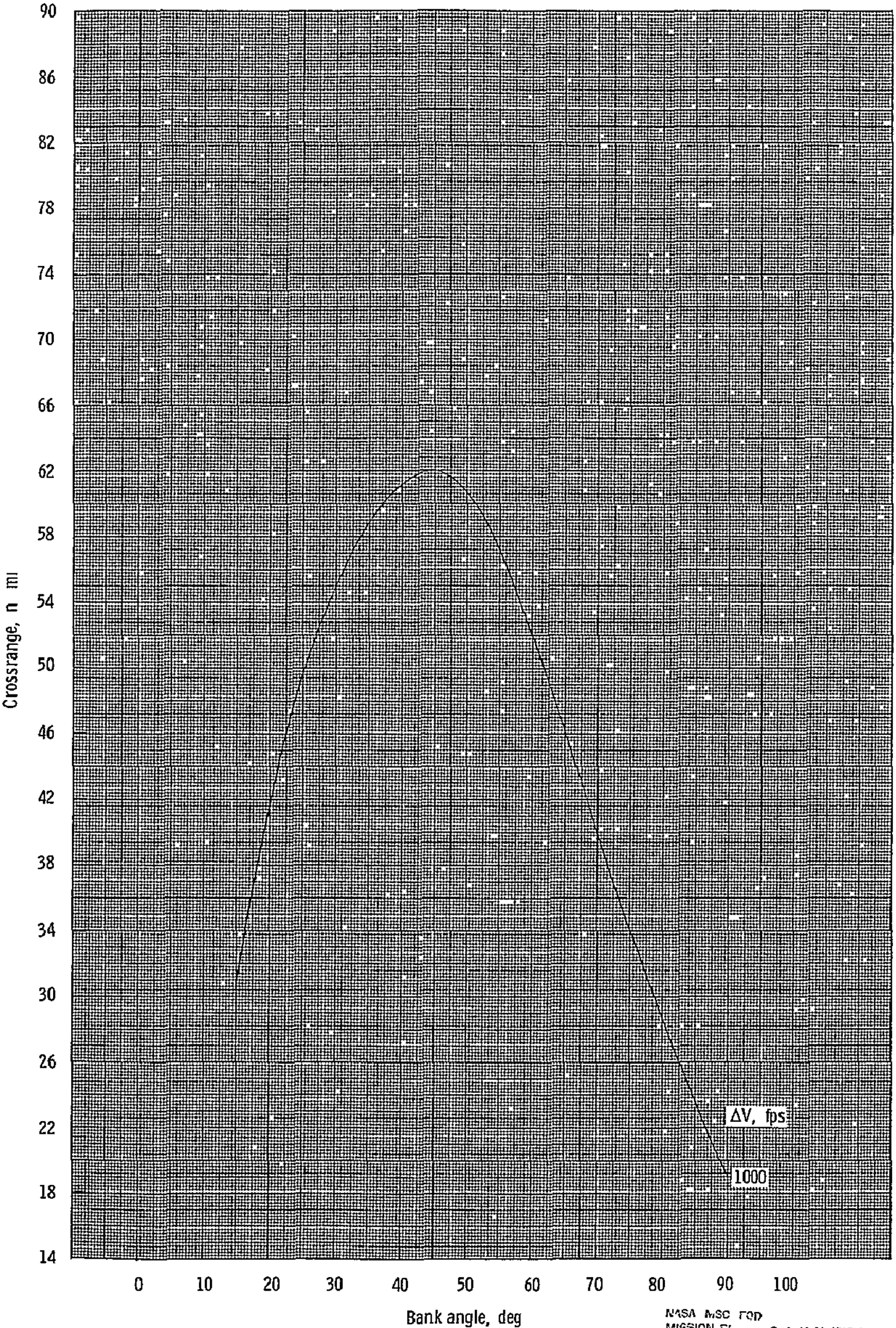
Figure 10 - Continued



ANALYSIS DIVISION
BRANCH
File No 17112h
Date March 23, 1966 DPS

(d) 200 nautical mile circular orbit.

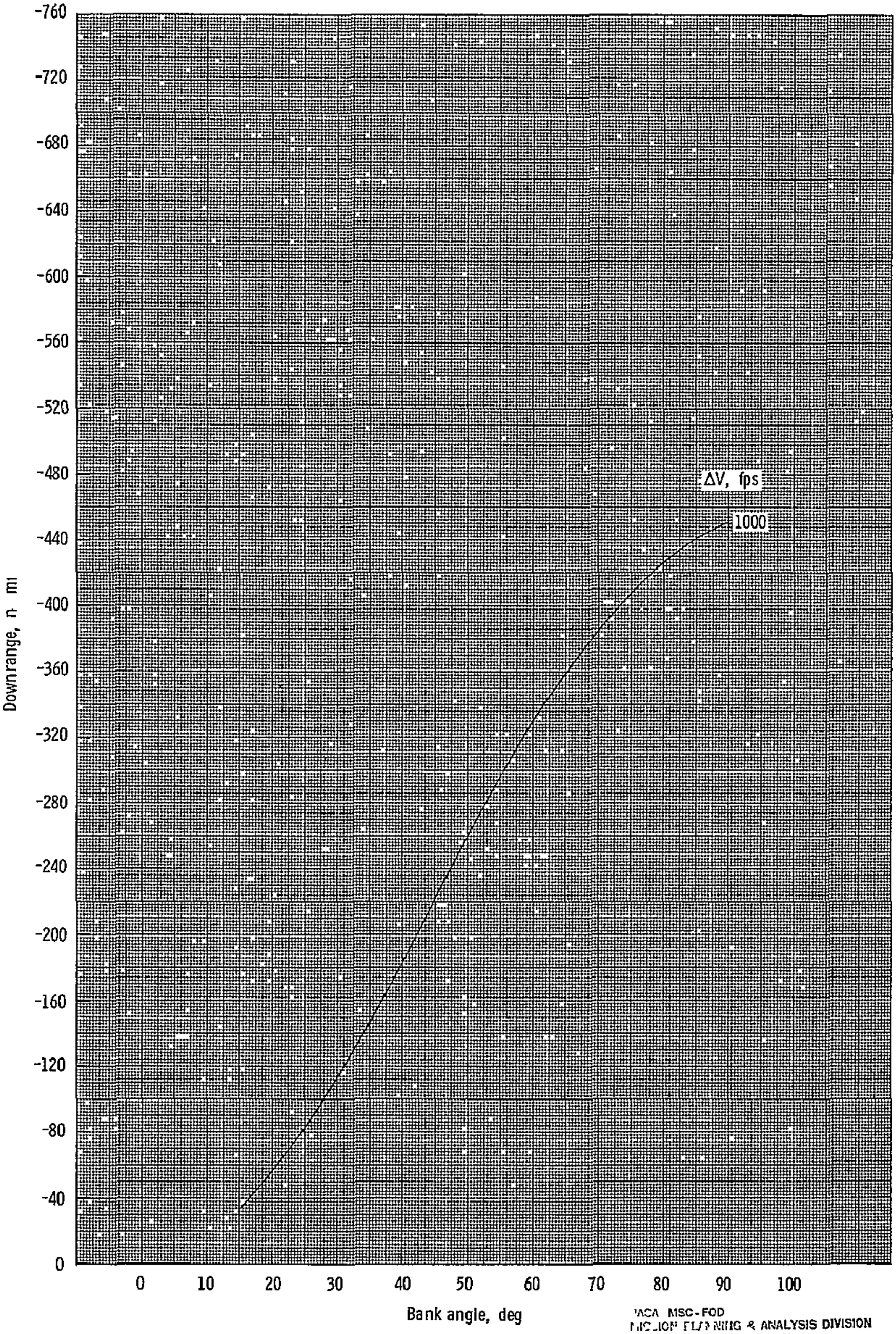
Figure 10 - Continued.



NASA MSC FOD
MISSION P... & ANALYSIS DIVISION
FLIGH...
Plot No 17112k
Date March 23, 1966 DPS

(e) 400 nautical mile circular orbit.

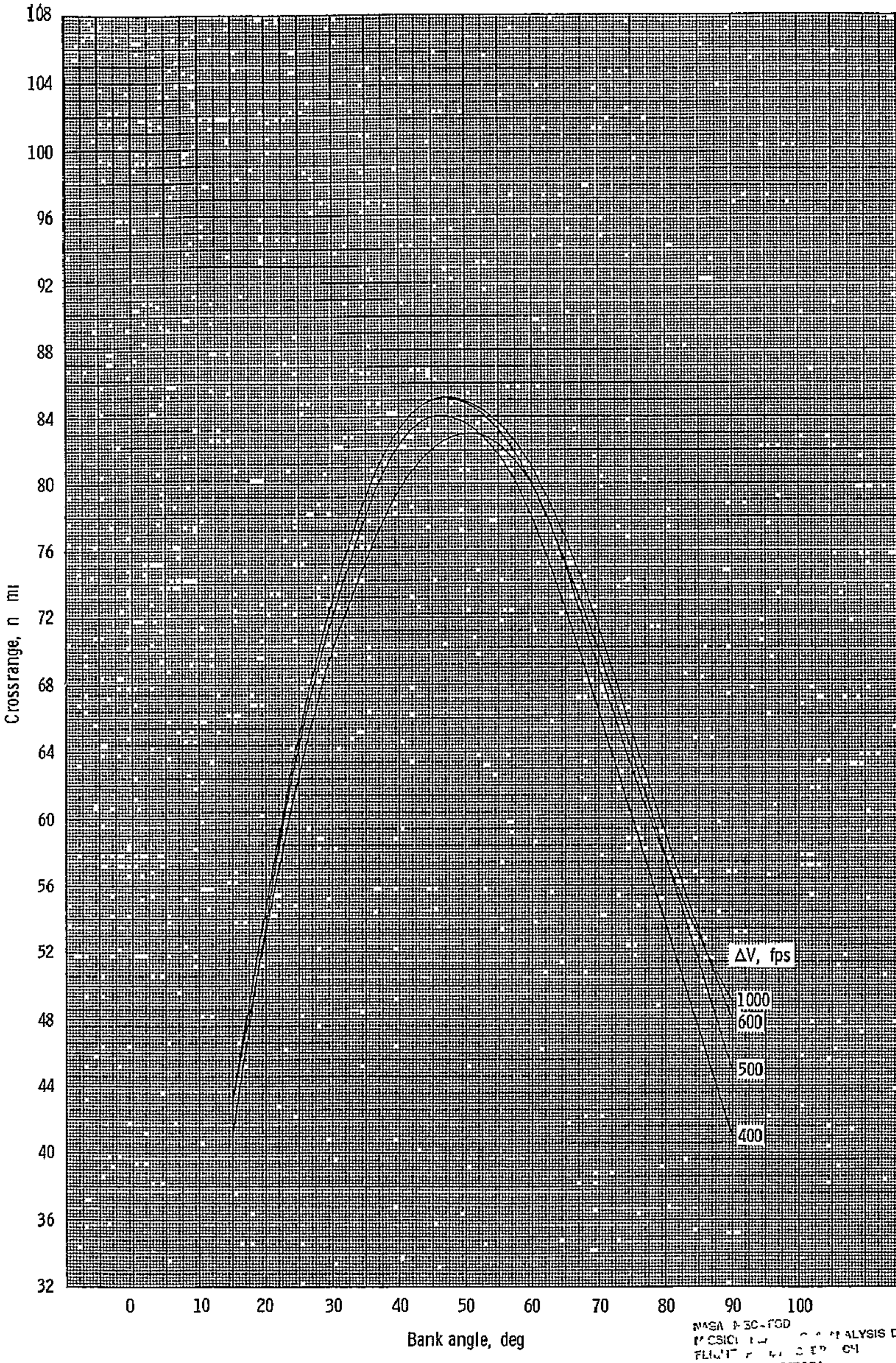
Figure 10 - Continued.



NASA MSC-FOD
MISSION PLANNING & ANALYSIS DIVISION
FLIGHT ANALYSIS BRANCH
Plot No 171121
Date March 23, 1966 DPS

(e) 400 nautical mile circular orbit.

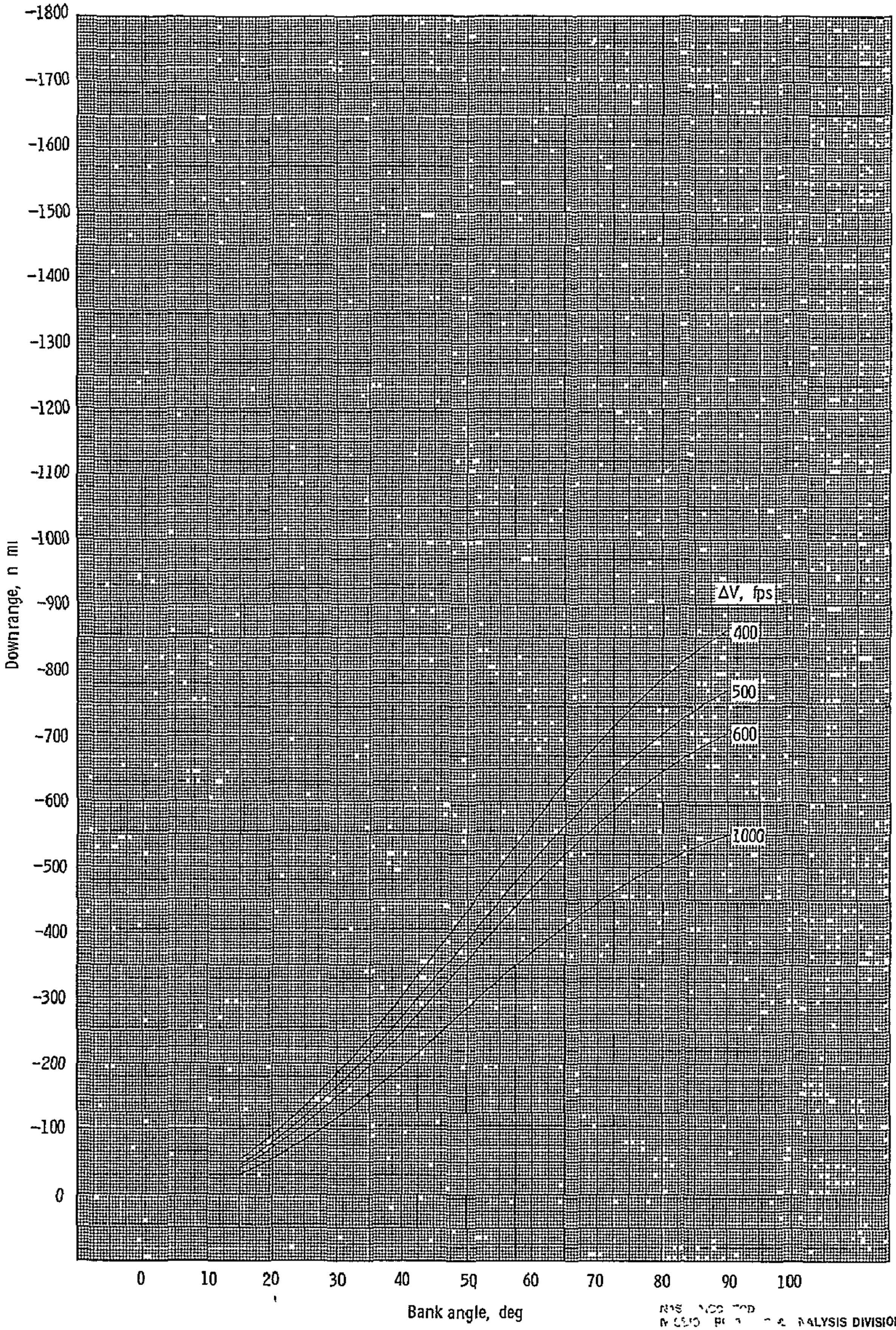
Figure 10. - Continued.



NASA MSC-FOD
ALYSIS DIVISION
Date March 23, 1966
171121
DPS

(f) 85/150 nautical mile elliptical orbit with burn at perigee

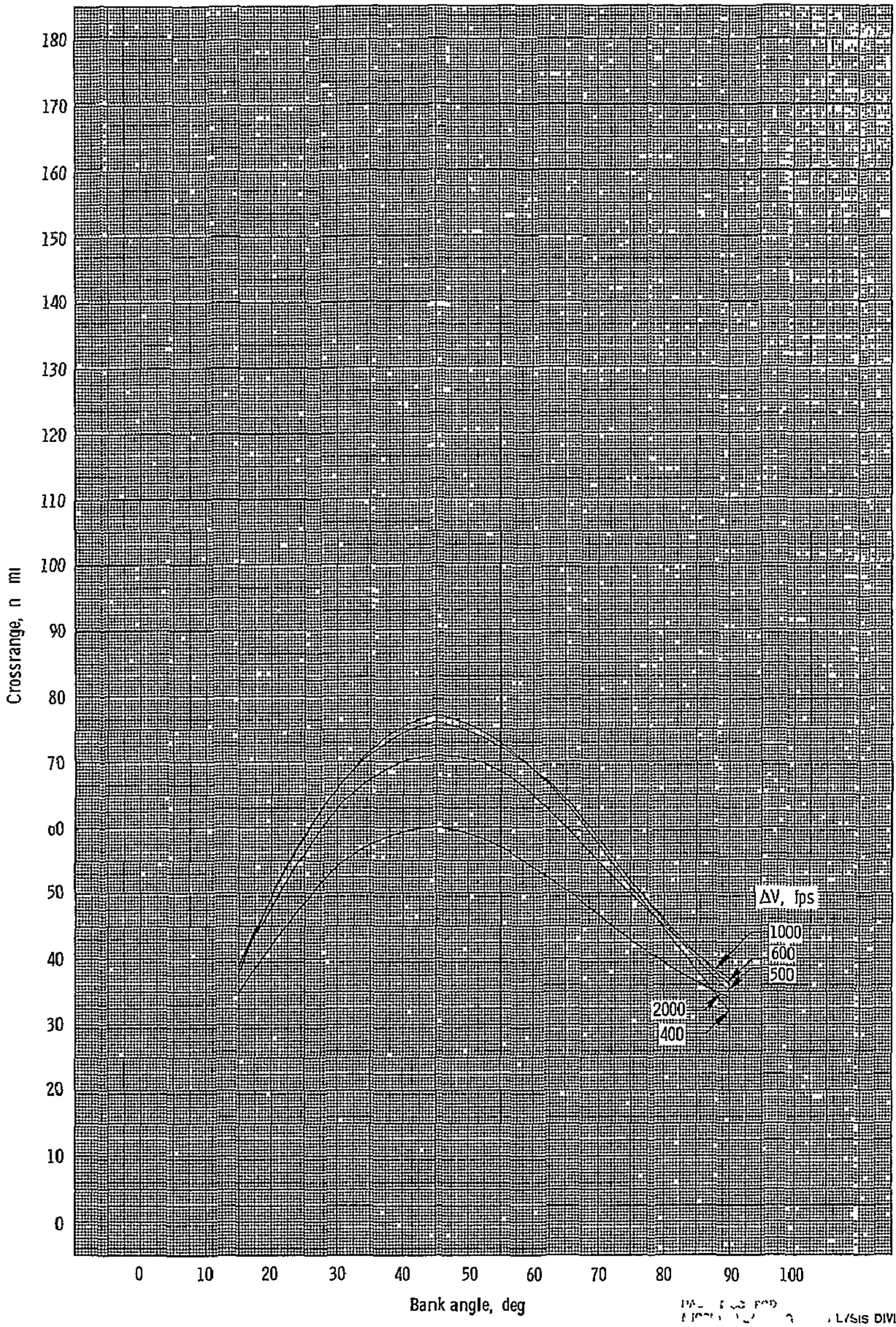
Figure 10 - Continued



ANALYSIS DIVISION
BRANCH
Plot No 171121
March 23, 1966 DPS

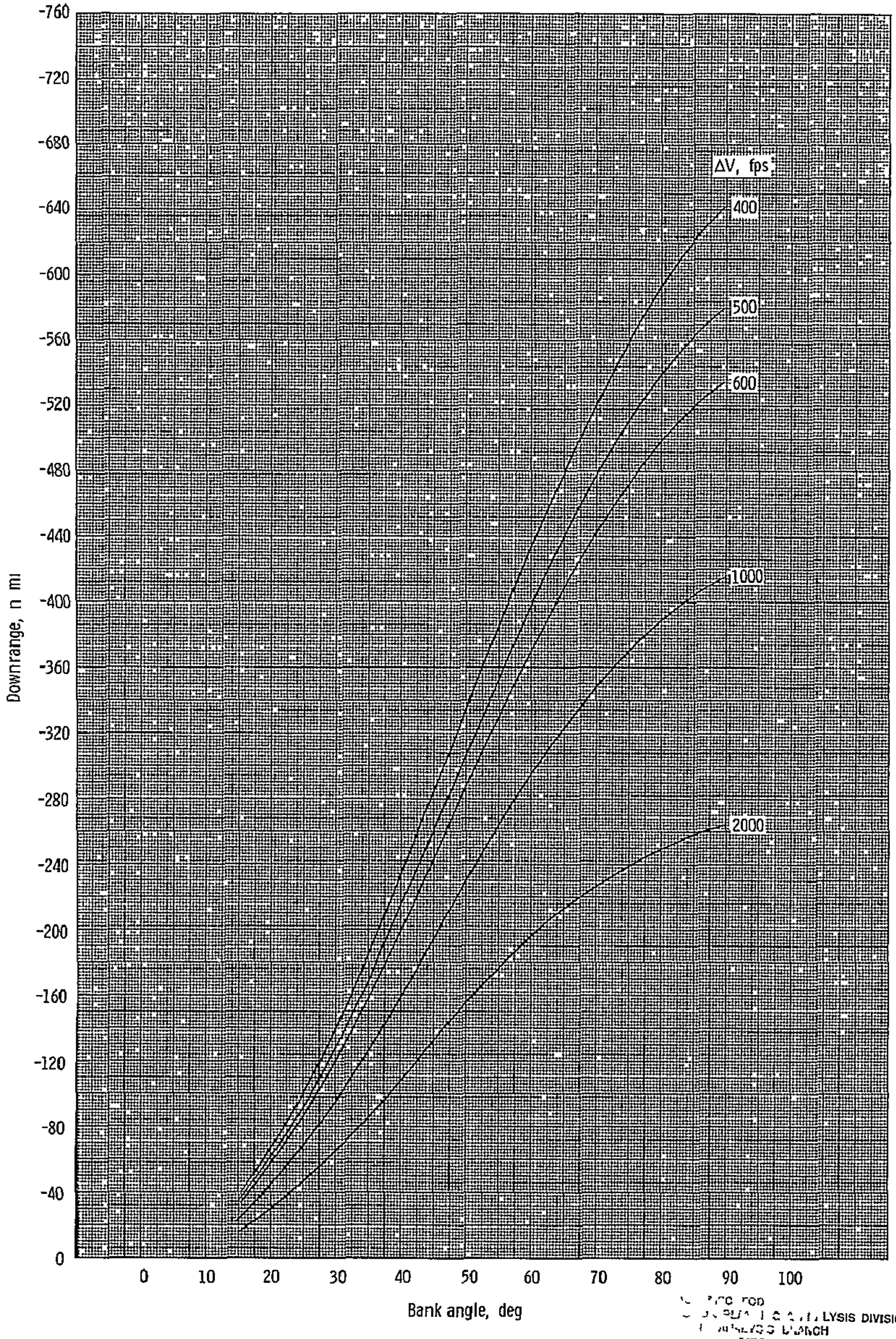
(f) 85/150 nautical mile elliptical orbit with burn at perigee

Figure 10 - Continued



L/SIS DIVISION
Plot No 17112m
Date March 23, 1966 DPS

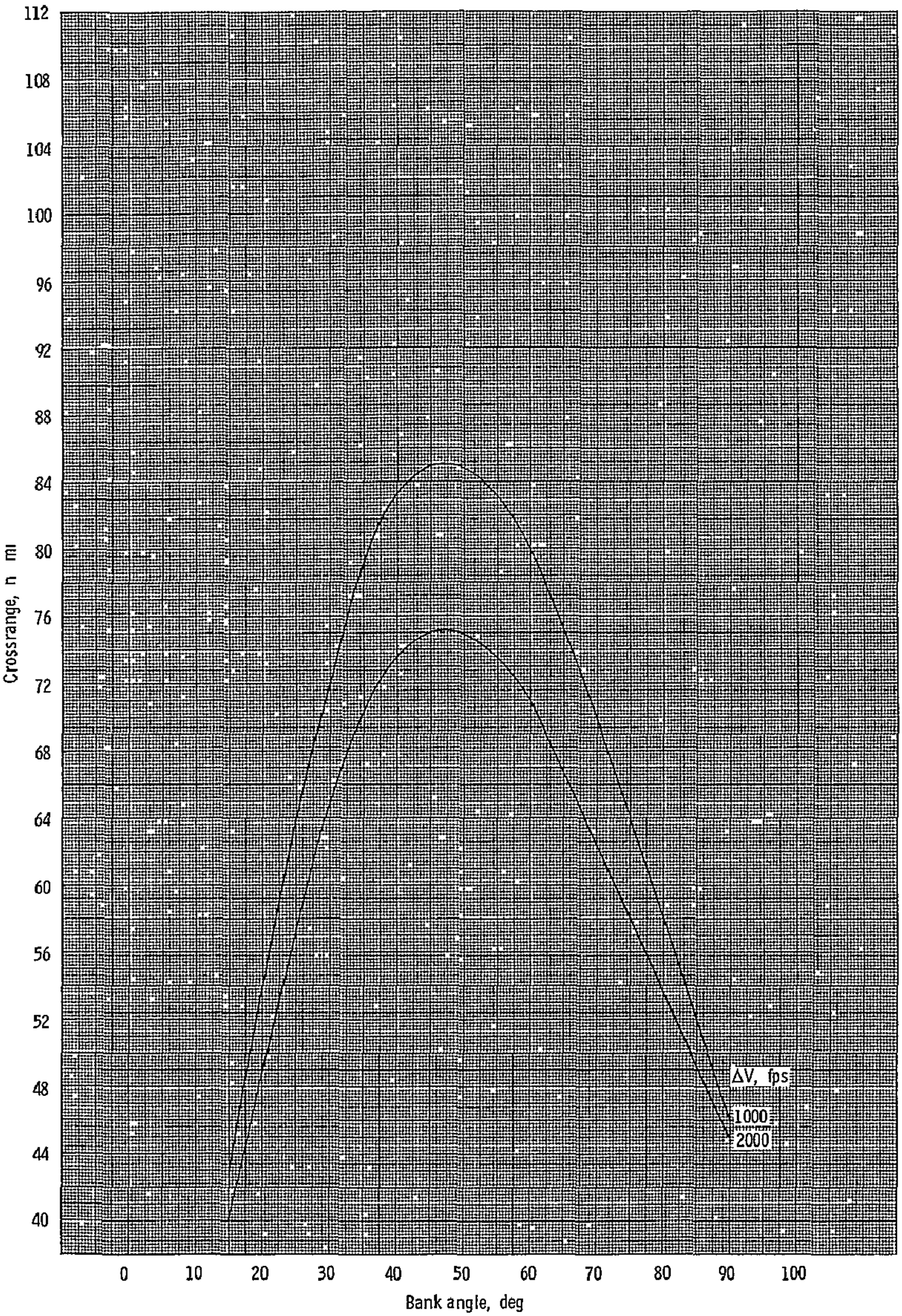
(g) 85/150 nautical mile elliptical orbit with burn at apogee



LYSIS DIVISION
BRANCH
17112n
March 23, 1966 DPS

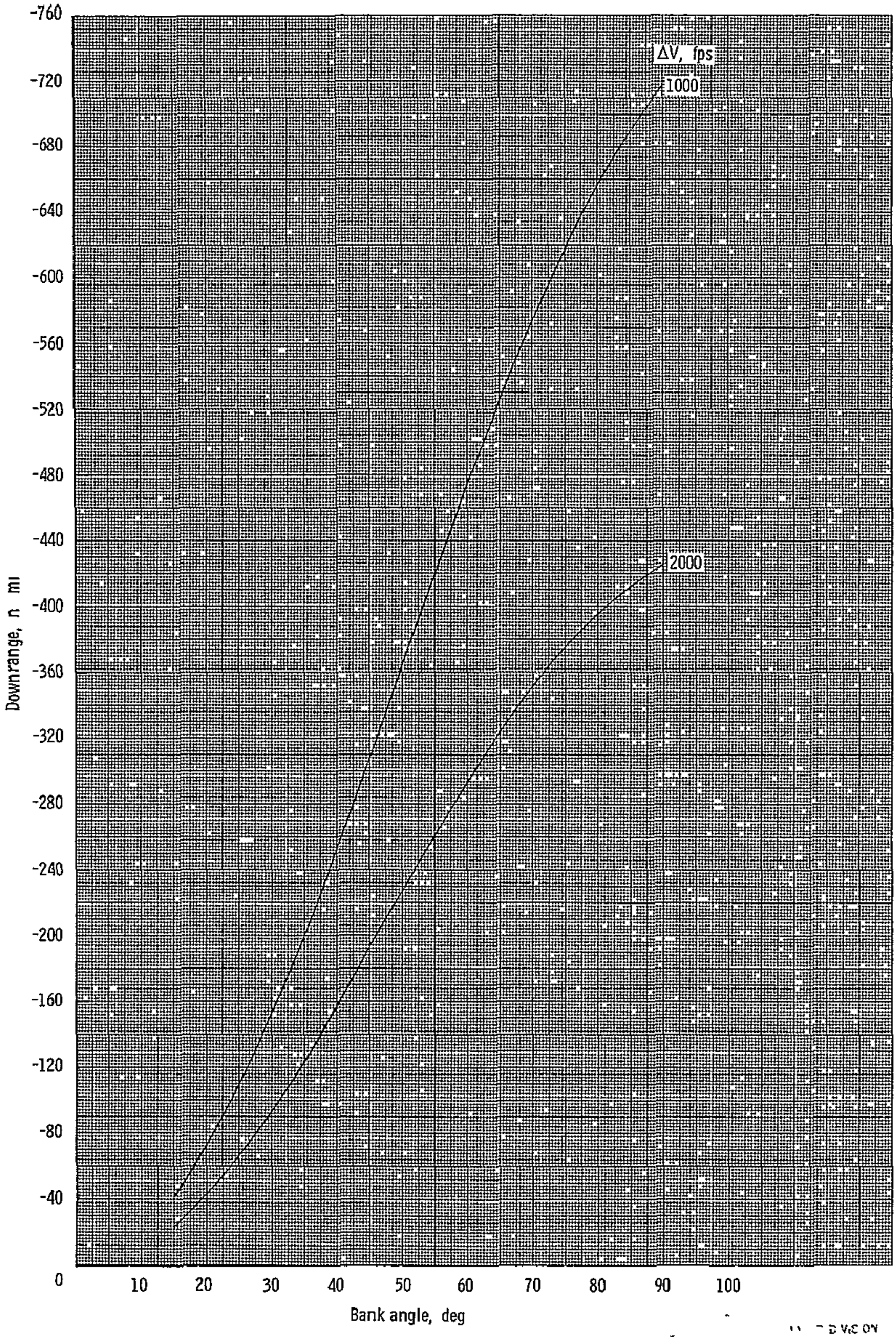
(g) 85/150 nautical mile elliptical orbit with burn at apogee.

Figure 10. - Continued.



(h) 85/400 nautical mile elliptical orbit with burn at perigee.

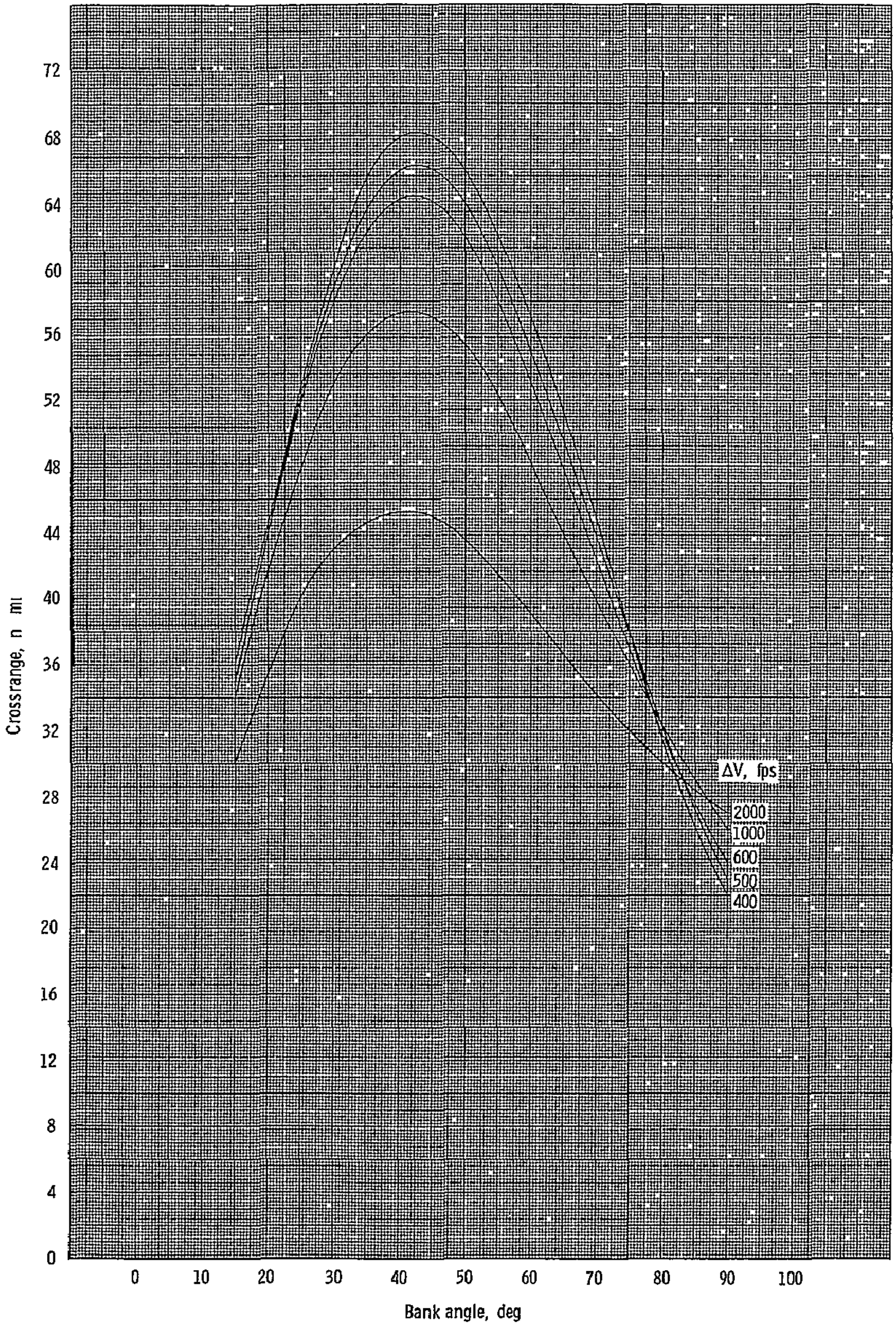
Figure 10. - Continued.



17112p
March 23, 1966 DPS

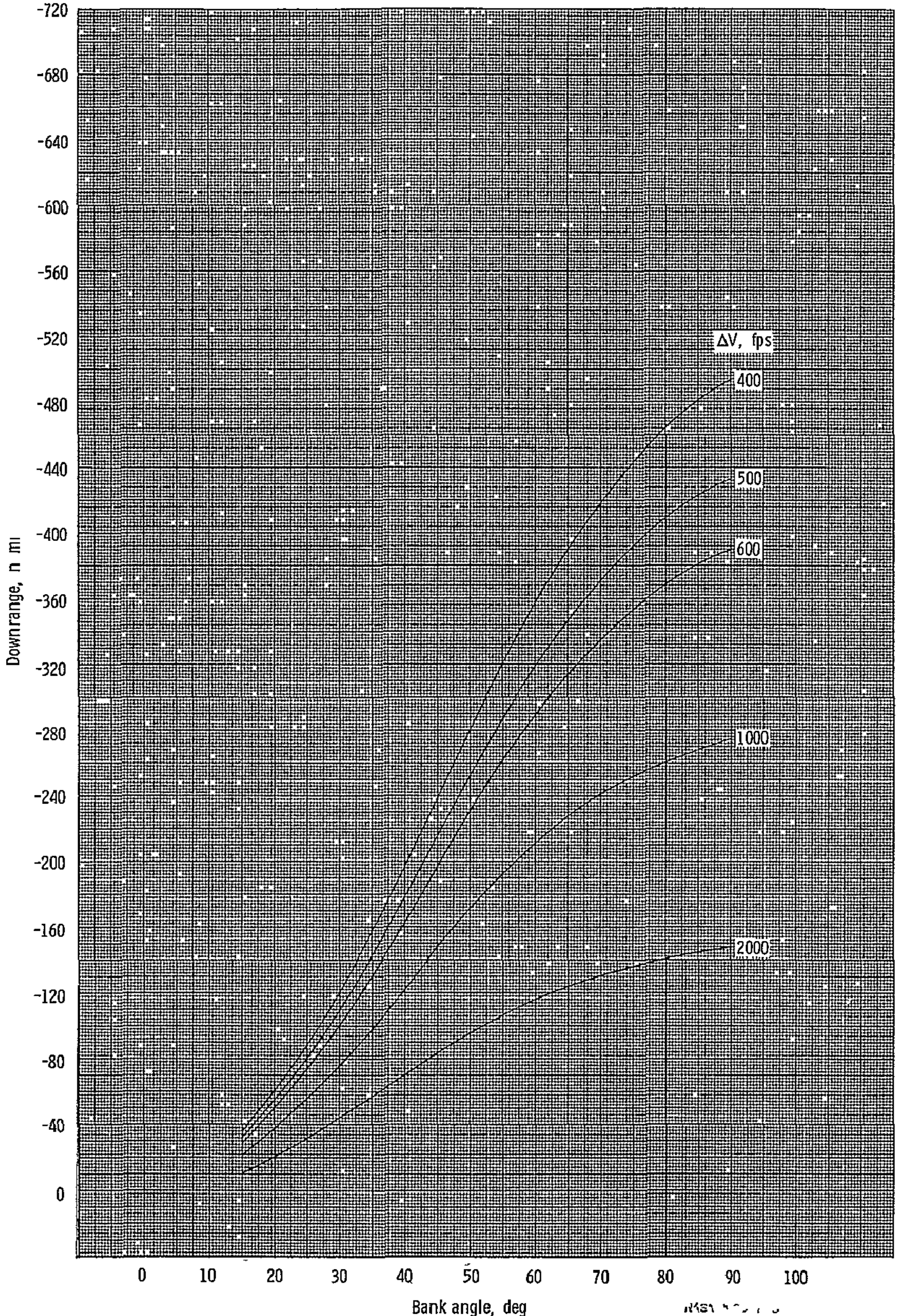
(h) 85/400 nautical mile elliptical orbit with burn at perigee.

Figure 10 - Continued.



(i) 85/400 nautical mile elliptical orbit with burn at apogee.

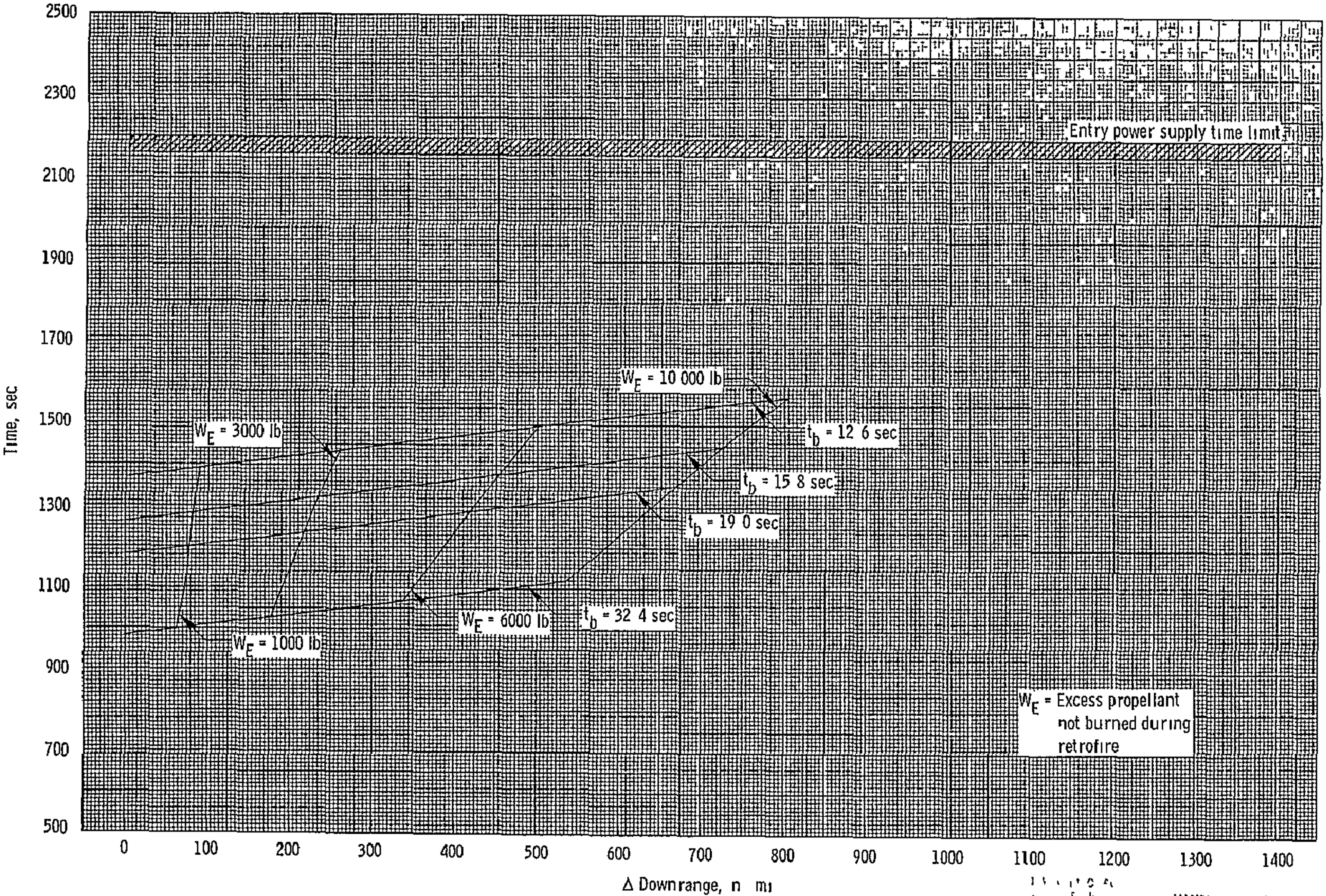
Figure 10 - Continued



SIS DIVISION
17112r
Date March 23, 1966 DPS

(i) 85/400 nautical mile elliptical orbit with burn at apogee

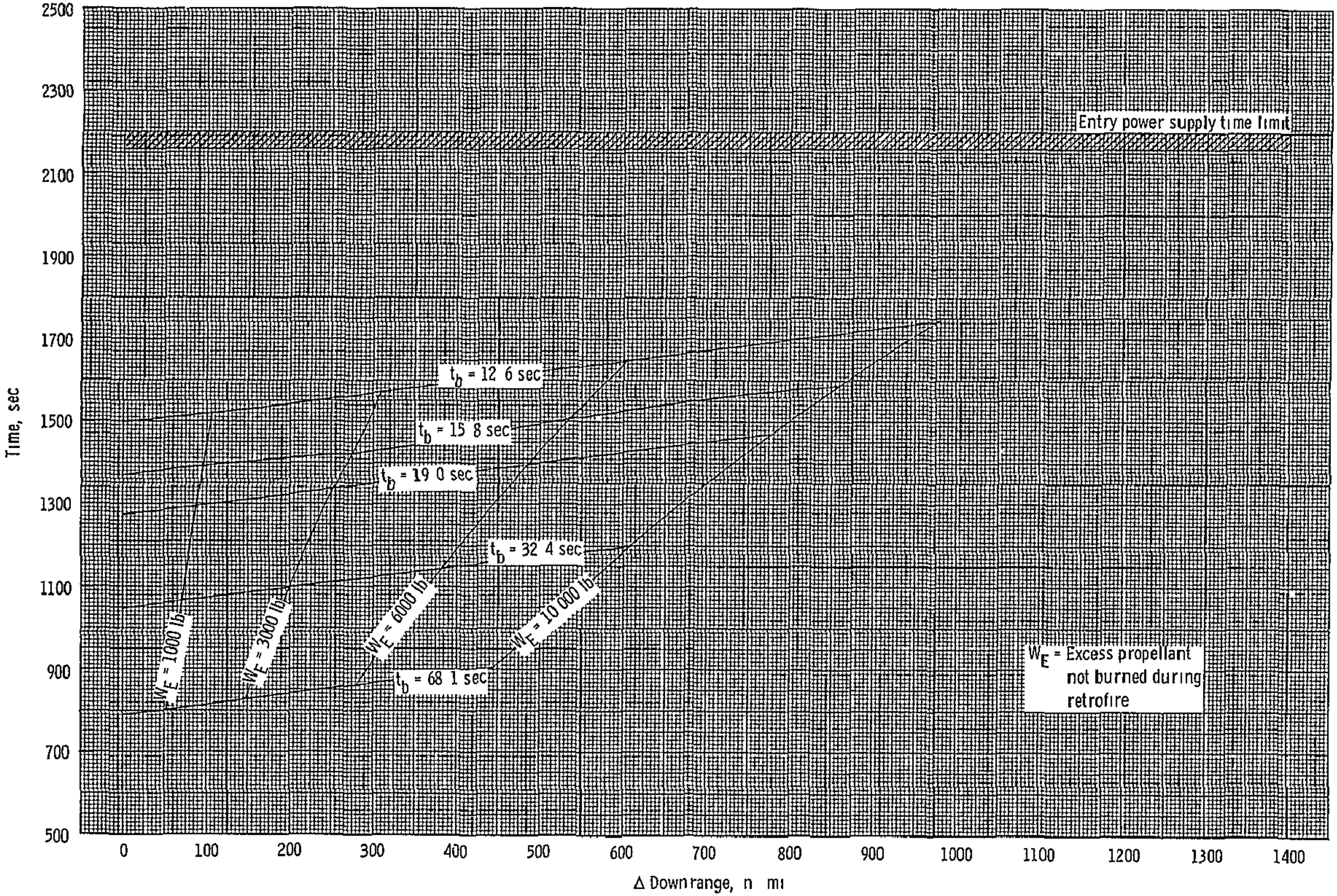
Figure 10 - Concluded.



ALYSIS DIVISION
17113a
Date March 23, 1966 DPS

(a) 85 nautical mile circular orbit

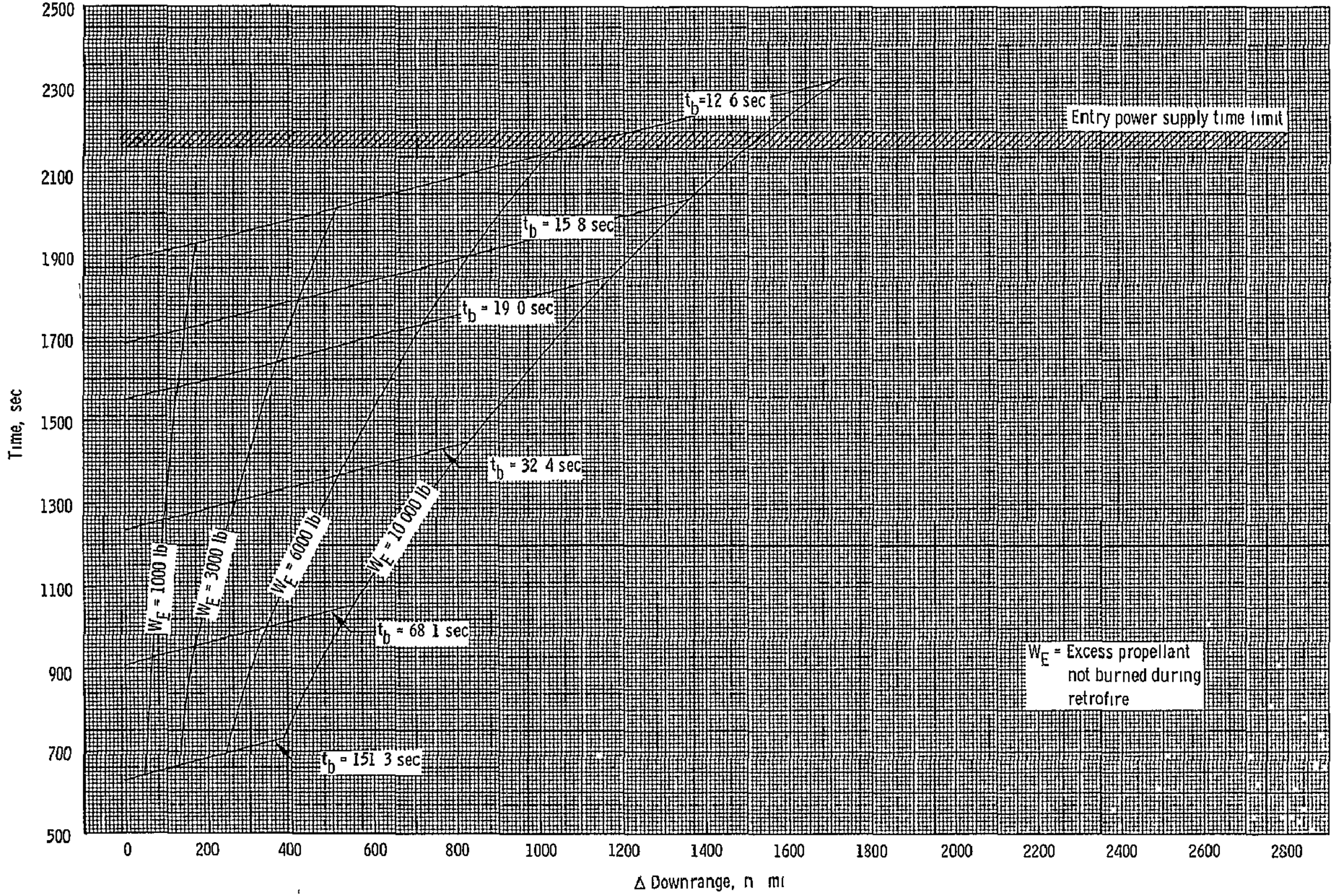
Figure 11 - Downrange versus time from end of burn for various burn times and excess propellant loadings at different orbital conditions



(b) 100 nautical mile circular orbit

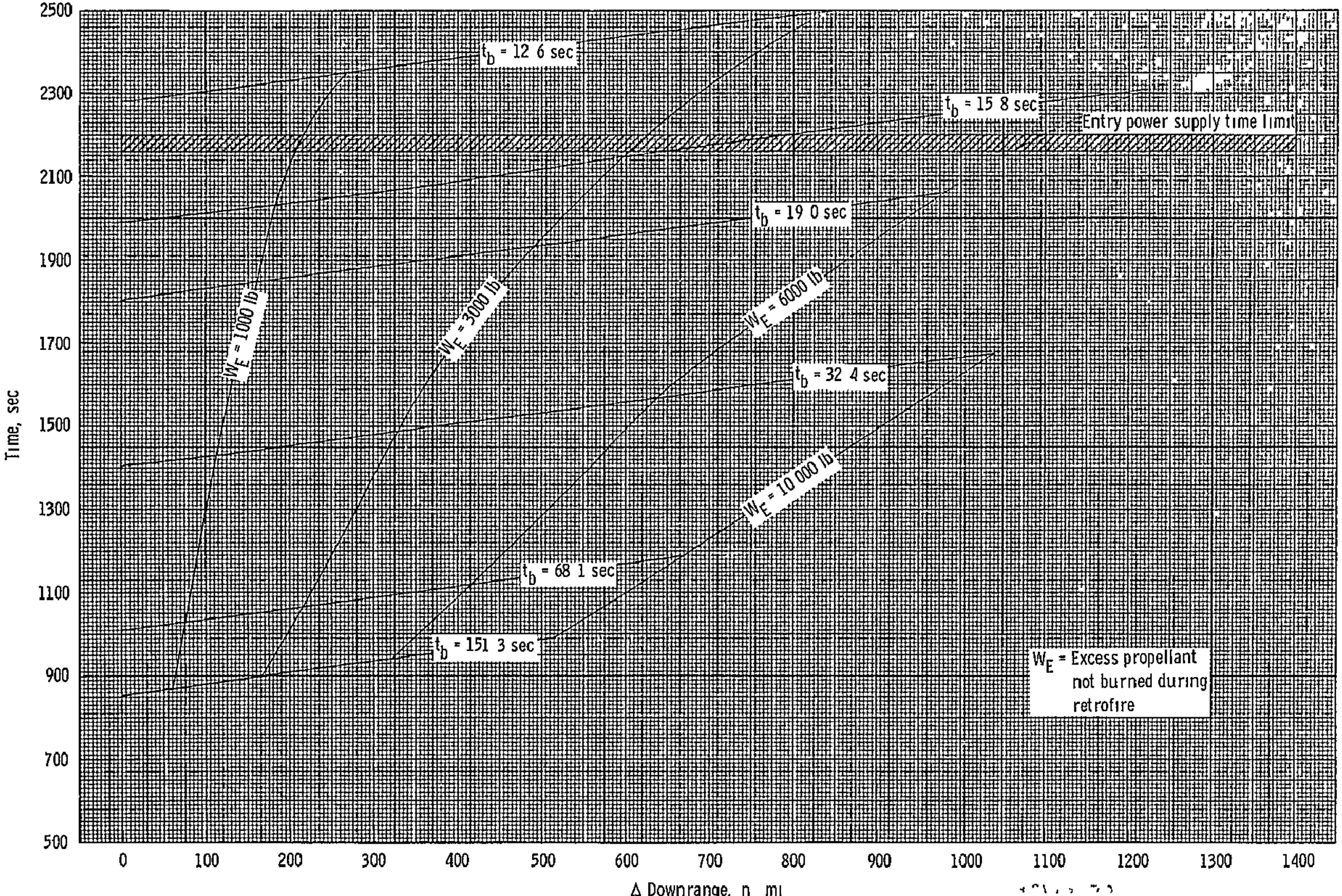
Figure 11 - Continued

17113b
March 23, 1966
DRS



(c) 150 nautical mile circular orbit.

Figure 11 - Continued

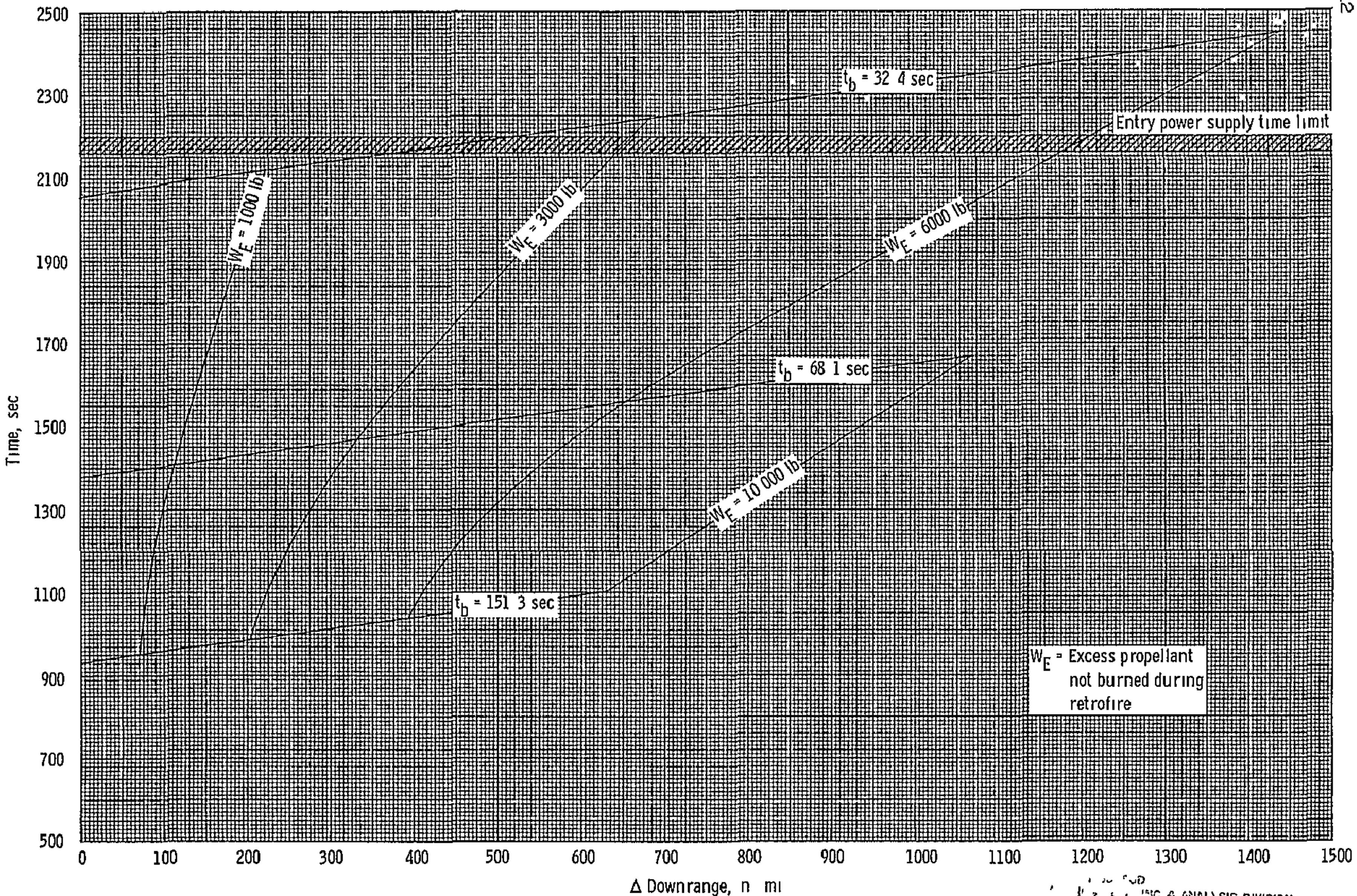


(d) 200 nautical mile circular orbit.

Figure 11 - Continued

17113d
March 23, 1966

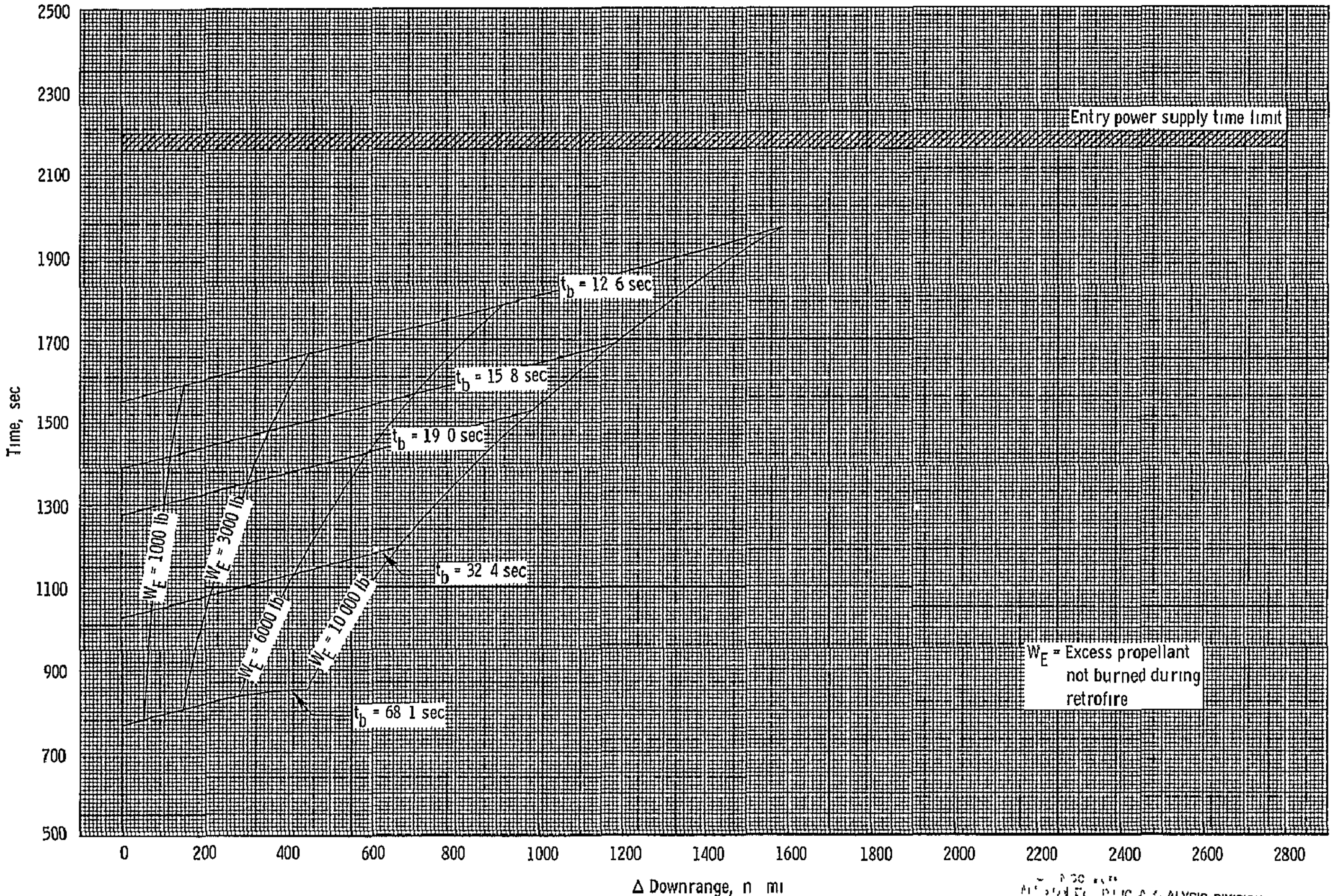
DIVISION
DPS



ANALYSIS DIVISION
BRANCH
Plot No 17113e
Date March 23, 1966 DRS

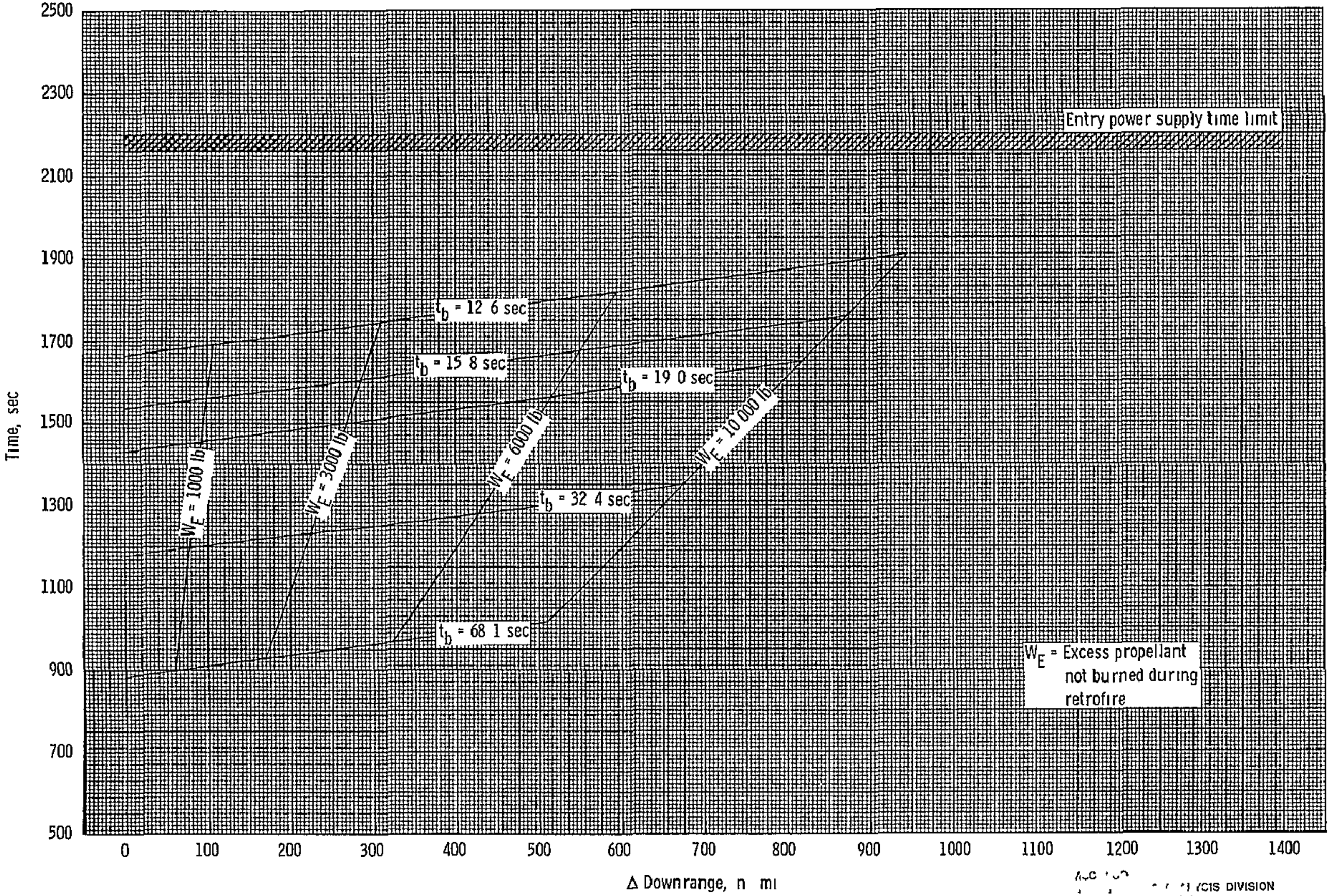
(e) 400 nautical mile circular orbit.

Figure 11. - Continued



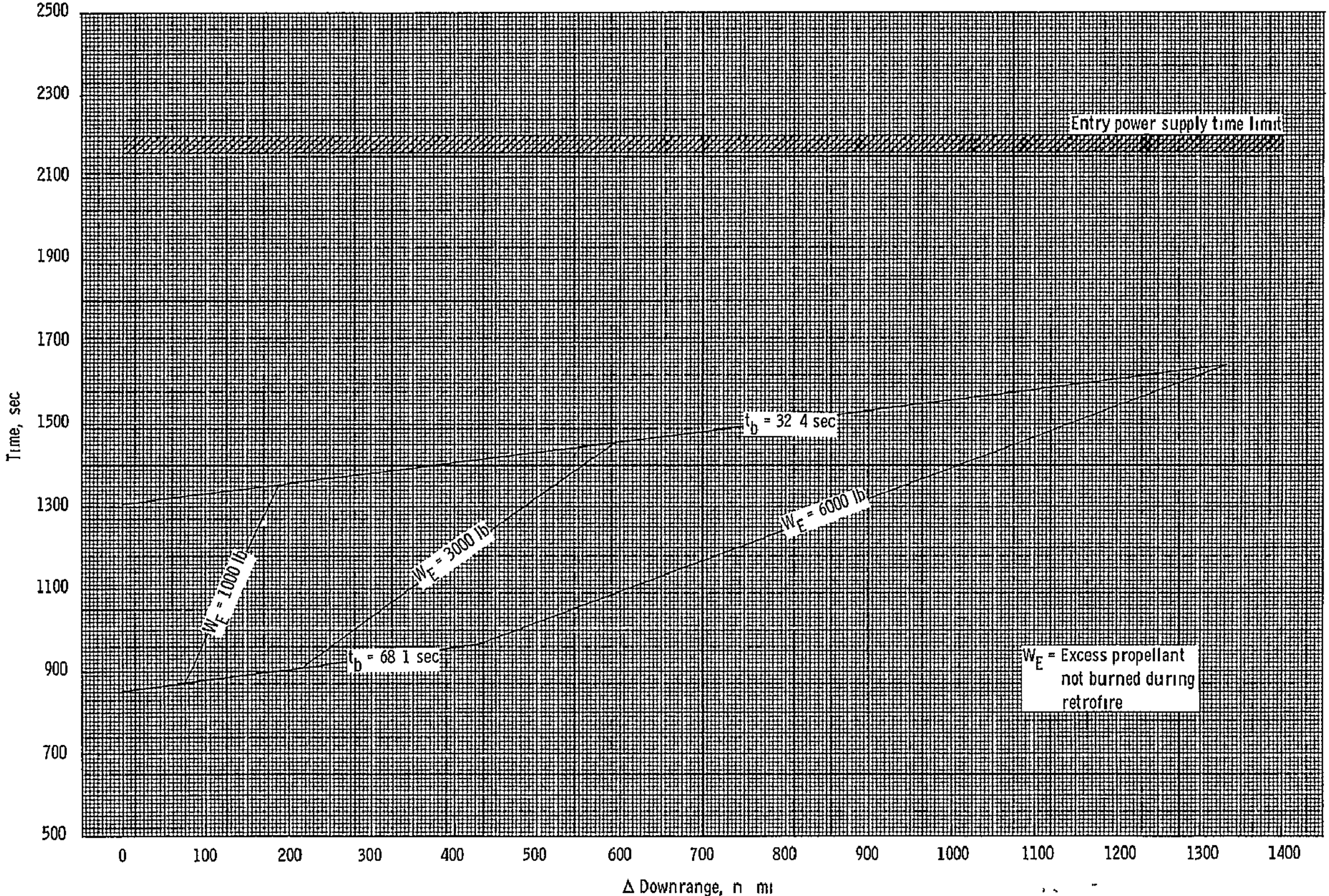
(f) 85/150 nautical mile orbit with burn at perigee

Figure 11 - Continued



(g) 85/150 nautical mile orbit with burn at apogee

Figure 11 - Continued



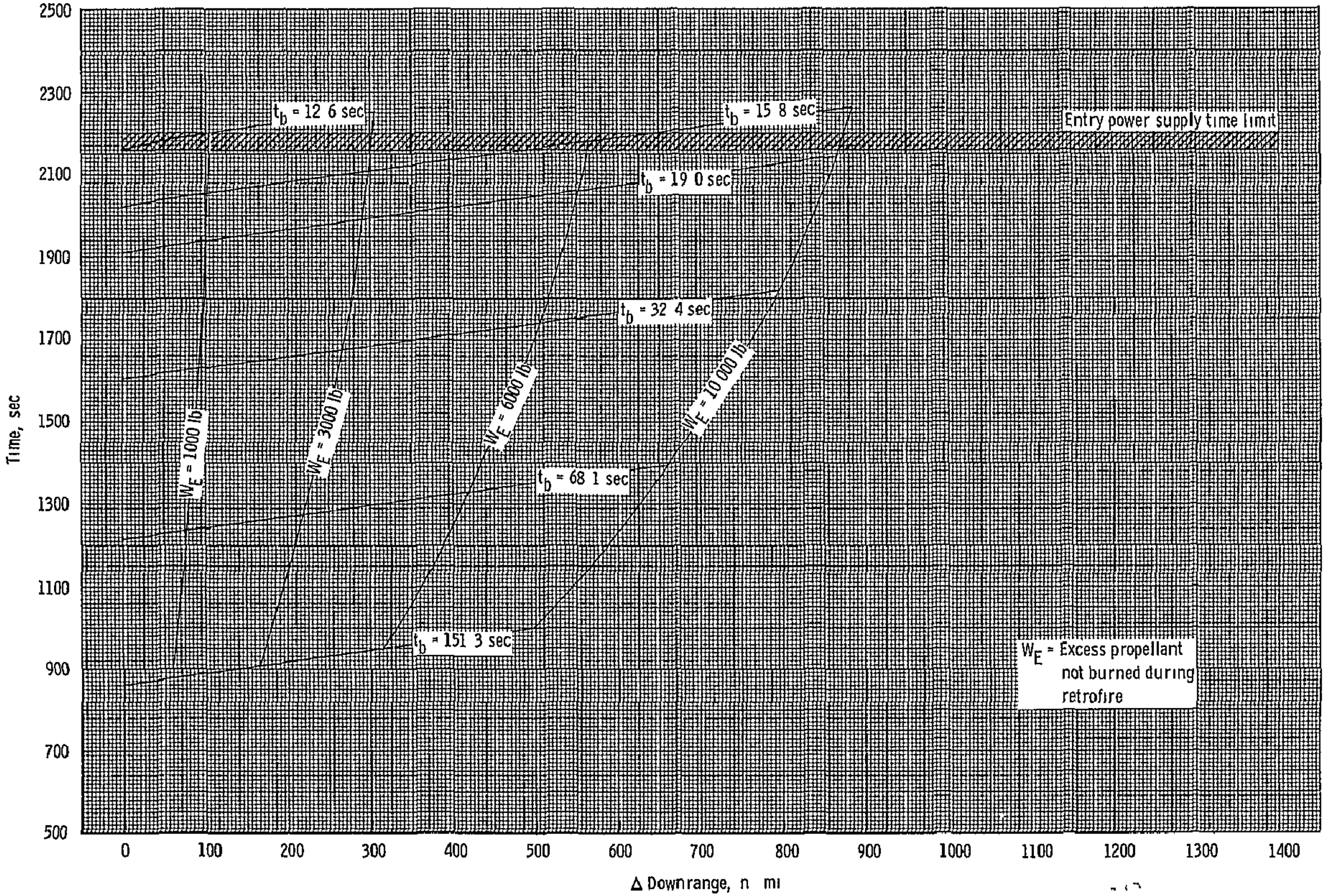
SIS DIVISION

17113h

Date March 23, 1966 DPS

(h) 85/400 nautical mile orbit with burn at perigee

Figure 11. - Continued



(i) 85/400 nautical mile orbit with burn at apogee.

Figure 11. - Concluded.

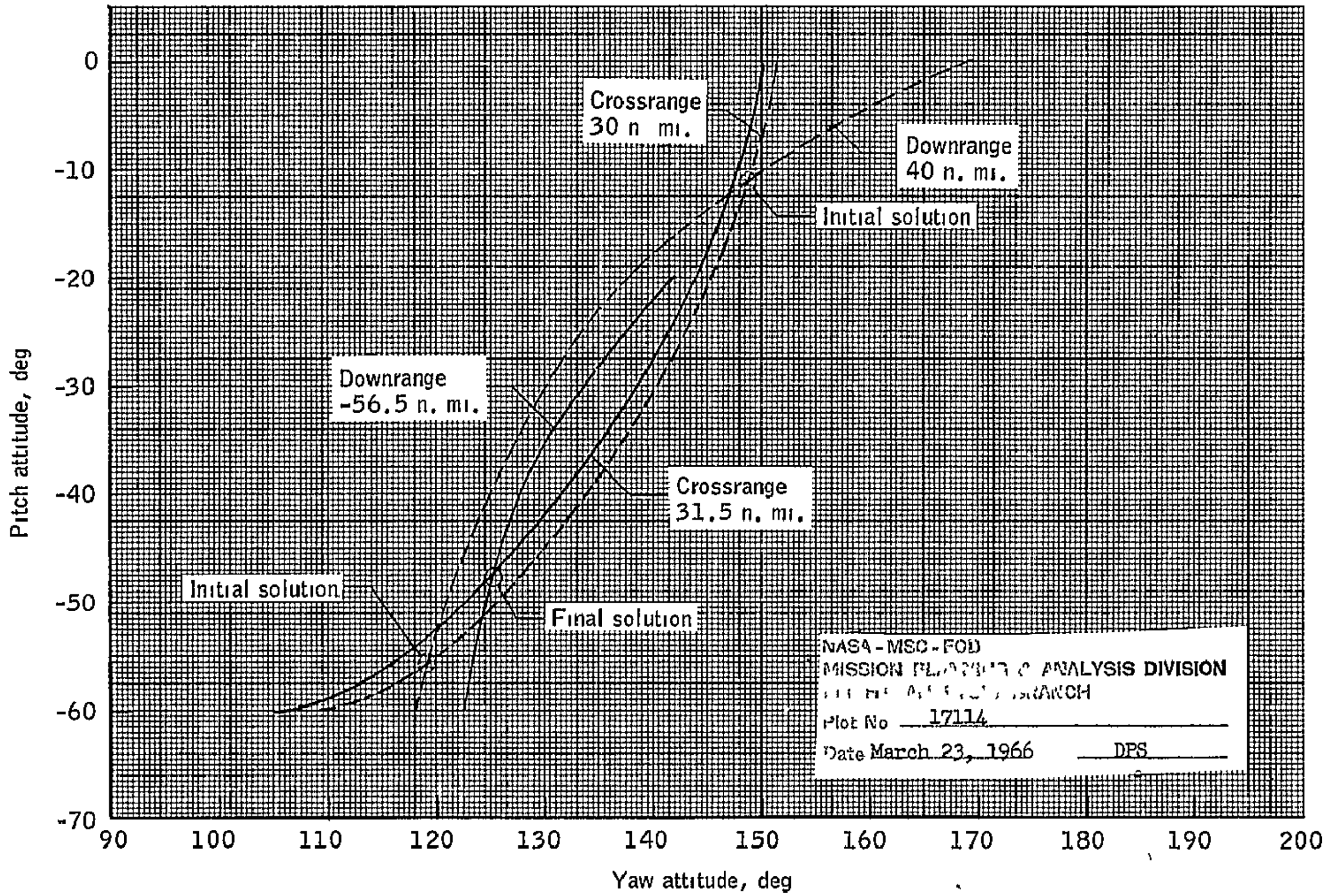


Figure 12.- Pitch versus yaw for example solution of correct attitude of burn.